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Interior View of the Laboratory in the Royal Institution.

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A
MANUAL
OF
CHEMISTRY;

CONTAINING

THE PRINCIPAL FACTS OF THE SCIENCE: ARRANGED IN THE ORDER IN WHICH THEY ARE DISCUSSED AND ILLUSTRATED IN THE LECTURES AT THE ROYAL INSTITUTION OF GREAT BRITAIN.

BY

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&c. &c. &c.

THE THIRD EDITION; IN TWO VOLUMES.

VOL. I.

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TO

CHARLES HATCHETT, Esq., F.R.S.,

&c. &c. &c.

My Dear Sir,

To you, as my first Instructor in Chemistry, and as one whose researches in the Science have exalted your name to a high station among British Chemists, I beg leave to dedicate the following Work; trusting that you will receive it as a testimony of the gratitude and respect with which I shall always remain,

Your faithful Friend,

and affectionate Son-in-Law,

William Thomas Brande.

London, May, 1830.

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Are published separately, and may be conveniently bound up with the First Volume.

PREFACE.

Though the following pages are chiefly intended for students, it is trusted that the proficient will find them a useful compendium of Chemistry.

The arrangement of the materials differs from that sanctioned by our best elementary writers, but it has been adopted in consequence of some years' experience of its advantages in teaching the principles of the science.

In the first chapter, the leading facts connected with the general laws of chemical changes are discussed under the separate heads of Attraction, Heat, and Electricity. The second chapter relates to the properties of Radiant Matter, and its influence upon the composition of bodies. In the third and fourth chapters I have detailed the sources and properties of the Simple Supporters of Combustion, and the Elementary Acidifiable Substances, and their mutual combinations. The fifth chapter contains an account of the Metals, and of their compounds with the bodies previously described, and with each other.

The sixth chapter embraces such details respecting the Assay and Analysis of Metalliferous Compounds, as are necessarily omitted under the individual history of the metals: in this division I have selected such instances as I conceived best adapted to assist the student in acquiring correct notions of this department of chemical study.

In the seventh chapter I have aimed at a succinct description of the means of analyzing mineral waters, and as their examination is frequently desirable where the conveniences of a regular laboratory are not attainable, I have subjoined a short account of the tests and apparatus required in this branch of research.

Upon the subject of analysis in general, the student will find inexhaustible information in the writings of Klaproth, Pfaff, and Stromeyer, and in the Essays of Vauquelin; the former have only been in part translated into the English language; and the latter are scattered through various periodical publications, especially the *Journal des Mines*, and the *Annales de Chimie*. The last thirty volumes of the *Philosophical Transactions* are also rich in detached essays, by our most eminent chemists, illustrative of the art of analysis. A judicious selection from these sources, upon an extended scale, would be truly valuable to the practical chemist, and would materially contribute to facilitate the progress of our analytical inquiries.

The eighth and ninth chapters are assigned to Vegetable and Animal Products.

In the present edition the subject of Geology has been entirely omitted, as embracing a variety of details not strictly chemical, and as occupying space which I have now consigned to other matter. I have also omitted the Tables of Specific Gravities and Equivalent Numbers, having published them separately upon an extended scale, and so arranged them that they may be conveniently bound up with either volume of this work.

A view of the interior of the Laboratory of the Royal Institution forms the frontispiece to this volume, and the second plate represents some of the most useful furnaces of the Laboratory.

Fig. 1. A sand furnace: *a* the larger bath; *b* the smaller one, which may occasionally be removed for the purpose of employing the fire-place for crucibles, or of inserting the boiler of a still.

Fig. 2. Section of a wind furnace: *a* is a flue communicating with the exterior of the building, for the admission of cold air to the fire-place; *b* the ash-hole; *c c* two grates, the upper of which may be removed when a deep fire-place is wanted; *d* an aperture which may be closed by a moveable fire-brick: *e* the chimney; *f* a register.

Fig. 3. Knight's portable furnace, made of wrought iron, and lined with fire-brick. It is convenient for a variety of operations, conducted upon a small scale: *a* is a door for the passage of the neck of a retort, when distillation is performing in the open fire; *b* is an aperture to which there is a corresponding one on the opposite side for the admission of a tube to pass through the furnace, as shown at page 172.

Fig. 4. A portable assay-furnace ; *a* is the muffle represented in *Fig*. 5.

Fig. 6, 7, and 8, are evaporating basins ; 9, a Platinum crucible and cover ; 10, 11, Hessian crucibles ; 12, 13, 14, 15, the principal varieties of tongs useful in the Laboratory.

HISTORY OF CHEMISTRY.

Chemistry is that branch of natural knowledge which teaches us the properties of the elementary substances, and of their mutual combinations; it inquires into the laws which affect, and into the powers which preside over their union; it examines the proportions in which they combine, and the modes of separating them when combined, and endeavours to apply such knowledge to the explication of natural phenomena, and to useful purposes in the arts of life*.

Chemistry cannot be said to have existed, as a science, previous to the commencement of the seventeenth century; for although we find, in the writings of the earlier chemists, many curious and important facts and discoveries, these remained

* *Definitions of Chemistry.*—"La Chymie est un art qui enseigne à separer les differentes substances qui se rencontrent dans un mixte." (L'Emery, *Cours de Chymie.*)

"Chemistry is that science which examines the constituent parts of bodies, with reference to their nature, proportions, and method of combination." (Bergman, *Essay on the Usefulness of Chemistry.*)

"Chemistry is the study of the effects of heat and mixture, with a view of discovering their general and subordinate laws, and of improving the useful arts." (Black, *Lectures.*)

"La Chimie est une science qui apprend à connaitre l'action intime et réciproque de tous les corps de la nature, les uns sur les autres. Par les mots *action intime,* et reciproque, cette science est distinguée de la physique experimentale, qui ne considère que les propriétés extérieures des corps doués d'un volume, et d'une masse quon peut mesurer, tandis que la Chimie ne s'attache qu'aux propriétés intérieures, et n'agit que sur des molécules, dont le volume et la masse ne peuvent pas être soumis aux mesures et aux calculs." (Fourcroy, *Systême des Connoissance Chimiques,* vol. i. p. 4.)

"Die Chemie ist eine Wissenschaft die uns die wechselseitige wirkungen der einfachern Stoffe in der Natur, die zusammensetzung der körper aus ihren und nach ihren verschiedenen verhältnissen, und die Art und Weise kennen lehrt, sie useless and unapplied, so long as the minds of men were exclusively directed to the transmutation of the metals, the fabrication of an universal elixir, and the production of the *Alcahest*, or general solvent. Although, therefore, it may often be amusing, and sometimes profitable, to revert to the crude spe-

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zu trennen, oder sie wieder zu neuen Körperarten zu verbinden." (Gren. *Systematisches handbuch der Chemie,* p. 1. Halle, 1794.)

"Chemistry is that science which treats of those events or changes in natural bodies, which are not accompanied by sensible motions." (Thomson, *System of Chemistry,* fifth edition, p. 2.)

"Most of the substances belonging to our Globe are constantly undergoing alterations in sensible qualities, and one variety of matter becomes, as it were, transmuted into another. Such changes, whether natural or artificial, whether slowly or rapidly performed, are called chemical;—thus the gradual and almost imperceptible decay of the leaves and branches of a fallen tree exposed to the atmosphere, and the rapid combustion of wood in our fires, are both chemical operations.

"The object of chemical philosophy is to ascertain the causes of all phenomena of this kind, and to discover the laws by which they are governed." (Davy, *Elements of Chemical Philosophy,* p. 1.)

In the latest editions of Johnson's *Dictionary,* the erroneous and antiquated definition of Boerhaave is very improperly retained. "An art whereby sensible bodies contained in vessels, or capable of being contained therein, are so changed by means of certain instruments, and principally fire, that their several powers and virtues are thereby discovered, with a view to philosophy or medicine."

The derivation of the word Chemistry can scarcely be said to have been ascertained. The most plausible guesses are the following: from χυω to melt, or χυμος juice; from *kema,* an oriental word signifying *black;* from χιμης, the name of a person eminently skilled in the sciences; from *Chêmi,* the Coptic name of Egypt, where the art is supposed to have had its rise.

According to Bryant (*Ancient Mythol.*), it is derived from *chemia,* and that word from *Cham.*

The Rev. Mr. Palmer, Professor of Arabic at Cambridge, has given the following etymology: "Al-chemy, or more properly Al-kemy, the knowledge of the substance or composition of bodies, so named from the substantive (Kyamon), that is, the substance or constitution of any thing; from the root (Kama). Golius. *Lexicon.*" (Thomson's *Chemistry,* 5th edit. p. 4. Note.)

Conversing upon this subject with my late friend Dr. Thomas Young, he remarked, that the Egyptians probably neither knew nor cared much about the *composition* of bodies; and that the term Chemistry, as referring to the secret art of transmutation, was probably derived from the Coptic root *hhems* or *chems,* signifying *obscure, dark.* The German word *geheim, secret,* he said, was perhaps of the same root.

"Hæc ars varia accepit nomina, nam omnium primò dicta fuit τέχνη ποιητικὴ, et antiquis illis temporibus per hanc vocem significabant artem vilia metalla in aurum convertendi, et ejus artifices ποιηταὶ vocari Zozimus dicit. Veteres Ægyptios hanc artem *Chimoet* vocasse Josephus Scaliger ibi ostendit, sed postea Græci hanc artem χϱυσοποιησιν dixerunt, Arabibus vero, *Alchemia.*" (Boerhaave, *Institutiones Chemiæ.*)

culations and waking dreams of the voluminous writers upon these subjects, who were eminent in the fourteenth and two successive centuries, the time of the student will be more usefully occupied in tracing the labours of those who, discarding visionary hypotheses, proceeded to the investigation of truth ; and who were led on, not by the vague glimmering of speculative notions, but by the steady daylight of real philosophy*.

It is, I think, among our own countrymen that we discover the fathers of chemical philosophy: for BACON, BOYLE, HOOKE, MAYOW, and NEWTON, present unequivocal claims to that distinctive title. As induction from experiment is exclusively the basis of chemical science, little progress could be made in it till the futility of the ancient philosophical systems had been shewn, and their influence annihilated; till the true end of science was rightly defined, and the road to it rendered straight and passable ; till the necessity of well-digested experiment had been established, which "first procures the light, then shews the way by its means."

It may seem trite to quote Lord BACON ; but, as experience is constantly showing the neglect of the invaluable doctrines inculcated in his works, and as students, especially, are too apt to throw off the burthen and responsibility of thinking for themselves, by adopting the notions of others, without either weighing their merit or appreciating their correctness, and often only because they are new, I shall beg leave to call their attention to one of the many relevant passages of this author.

"He who would come duly prepared, and fitted to the business of interpretation, must neither be a follower of novelty, custom, nor antiquity ; nor indulge himself in a liberty of contradicting ; nor servilely follow authority. He must neither

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* "Tout ce qu'on a dit de l'antique origine de la Chimie, sur les premiers hommes qui ont travaillé les metaux, taillé et poli les pierres dures, fondu les sables, dissous et crystallisé les sels, ne montre à un esprit exact et sévère qu'une vaine et ridicule pretension, semblable à cette par laquelle on voudrait reconnoître les élémens de la géométrie dans l'ouvrage grossier du sauvage qui use les fragmens du rocher, qui leur donne des formes à peu près régulières pour les rendre utiles à ses premiers besoins." (Fourcroy, *Discours Préliminaire.*)

be hasty in affirming, nor loose and sceptical in doubting; but raise up particulars to the places assigned them by their degree of evidence and proof. His hope must encourage him to labour, and not to rest; he must not judge of things by their uncommon nature, their difficulty, or their high character; but by their just weight and use. He must, in his own particular, carry on his view with concealment, and yet have a due regard for posterity. He must prudently observe the first entrance of errors into truths, and of truths into errors, without despising or admiring any thing. He must understand his own talents and abilities, or the advantages of his own nature. He must comply with the nature of others. He must, as with one eye, survey the natures of things, and have the other turned towards human uses. He must distinctly understand the mixed nature of words; which is extremely capable both of prejudicing and assisting. He must lay it down to himself, that the art of discovering will grow up, and improve, along with discoveries themselves. He must not be vain either in delivering or concealing the knowledge he has acquired; but ingenuous and prudent, and communicate his inventions without pride or ill-nature: and this in a strong and lively manner, well defended against the injuries of time, and fit for the propagation of knowledge, without occasioning errors; and, which is the principal thing of all, it must be such as may select and choose for itself a prepared and suitable reader *."

The following observations from the same source will bring me back to my subject:—

"And again; if any one should condescend to regard such things as are accounted rather curious than useful; and take a thorough view of the works of the alchymists, or the followers of natural magic; he might, perhaps, be at a difficulty which he should withhold, his tears, or his laughter. For the alchymist goes on with an eternal hope; and where his matters succeed not, lays the blame upon his own errors; and

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* *Prefatory Aphorisms of the Novum Organum Scientiarum.* No. XI.

accuses himself as not having sufficiently understood either the terms of his art, or his author: whence he either hearkens out for traditions and auricular whispers, or else fancies he made some mistake as to the exact quantity of the ingredients, or nicety of the experiment; and thus repeats the operation without end. And if, in the mean time, among all the chances of experiments, he throws any which appear either new or useful, he feeds his mind with these as so many earnests; boasts and extols them above measure; and conceives great hopes of what is behind. It must, indeed, be allowed that the alchymists have made many discoveries, and obliged mankind with useful inventions; but they are well represented in that fable of the old man, who left an estate to his children, buried somewhere or other, he told them, in his vineyard; which they, therefore, fell to dig for with great diligence; whereby, though they found no gold in substance, yet they received a better vintage for their labour.

"But such as apply to natural magic, and explain every thing by sympathies and antipathies, have, by supine and indolent conjectures, placed strange virtues and operations in things; and if, at any time, they have produced works, they are rather suited to admiration and strangeness, than to fruit and advantage*."

It is my intention, in this introductory chapter, after a brief allusion to the style and views of the alchymical writers, to notice the principal researches of the chemists of the fifteenth and two following centuries; and thus to give an historical sketch of the science, from its early days, to the commencement of the present age.

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* *Novum Organum.* Section V.

§ I.

The transmutation of baser metals into gold and silver, which was the chief, and, in most cases, the only object of the genuine alchymists, was not merely regarded as possible, but believed to have been performed, by some of the more enlightened chemists of the seventeenth century; and, in perusing the history of these transmutations, as recorded by Helvetius, Boerhaave, Boyle, and other sober-minded men, it would be difficult to resist the evidence adduced, without the aids of modern science. Lord Bacon's sound sense has been arraigned for his belief in alchymy, though he in fact rather urges the possibility than the probability of transmutation; and, considering the infant state of the experimental sciences, and of chemistry in particular, in his age, and the plausible exterior of the phenomena that the chemists were able to produce, he is rather to be considered as sceptical than credulous, upon many of the points which he discusses.

Hermes Trismegistus, who is said to have lived in the year of the world 2076, has generally been quoted as the oldest of the alchymists; there can, however, be very little doubt that the writings attributed to him are entirely spurious. The *Tractatus Aureus*, or *Golden Work*, is evidently a farrago of occult philosophy belonging to a much later period. Hermes, at the outset, is made to apologize for divulging the secrets of the black art. "I should never have revealed them," says he, "had not the fear of eternal judgment, or the hazard of the perdition of my soul, prevailed with me, for such a concealment. It is a debt I am willing to pay to the just, even as the Father of the just has liberally bestowed it upon me." After this prelude, we might expect to be let into some of the mysteries of alchymy, but our curiosity is quickly disappointed, by finding that they are only revealed to the eyes and ears of the sons of art; "not to the profane, the unworthy, and the scoffers, who, being as greedy dogs, wolves, and foxes, are not to feed at our divine repast." The reader is then conducted into what is termed the *innermost chamber*, and regaled with a history and explanation of various matters relating to the philosopher's stone, by means of which, "through the permission of the Omnipotent, the greatest disease is cured, and sorrow, distress, evil, and every hurtful thing evaded; by help of which we pass from darkness to light, from a desert and wilderness to a habitation and home, and from straightness and necessities to a large and ample estate." We are then directed to "catch the flying bird," by which is meant quicksilver; "and drown it so that it may fly no more:" this is what is afterwards termed the *fixation* of mercury, by uniting it to gold. It is then to be plunged into the "well of the philosophers," or *aqua regia*, "by which its soul will be dissipated, and its corporeal particles united to the red eagle," or muriate of gold.

We may, however, at once cut short these observations by remarking, that all the details bear upon increasing the weight of Gold by the influence of mercury, and this imaginary document of HERMES will suffice as an example of all the earliest alchymical authors.

GEBER is another great name in the history of alchymy *; though the exact period at which he lived is unknown, it was

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"* Primus omnium Arabum post Græcos est *Geber*, cui dant titulum Arabis. Alii dicunt eum fuisse regem, unde *rex Geber Arabs*, dici solet; sed *Leo Africanus* qui Græcus fuit et multa descripsit ex antiquis Arabibus, dicit, Gebrum illum natione Græcus fuisse, sed derogasse suam religionem, et se dedisse Mahomedæ religioni Arabum, et vixisse septimo seculo." (Boerhaave.)

Geber was also a physician and astronomer. The following are the principal works on Chemistry which have been attributed to him: *De Alchemia*,—*De summâ perfectione Metallorum*,—*De Lapide Philosophico*,—*De inveniendi arte Auri et Argenti*. These, and some other works bearing his name, whether genuine or not, furnish good specimens of the early alchemical writings.

probably not later than the seventh century. His three books of alchymy were published at Strasburgh, in 1520, and, if genuine, of which there is much doubt, contain matter that well justifies the praise of BOERHAAVE, who considers him as a first-rate philosopher of his age. In his chapter *On the Alchemie of Sol*, after descanting upon the different means of refining and dissolving gold, he describes several solar medicines in language which is tolerably intelligible; they are all solutions of gold in nitro-muriatic acid, with the addition of quicksilver, nitre, common salt, and some other saline matters, and the student is directed to prepare his mind for their performance by suitable acts of piety and charity, which if earnestly and perseveringly carried on, may, after due time, enable him in the language of his translator, Dr. SALMON, "to change argent vive into an infinite solific and lunific, without the help of any thing more than its multiplication." Alembics, crucibles, and various furnaces are so fully described, and, if we may believe the MSS., depicted by GEBER, that he deserves to be mentioned also as the inventor of much useful apparatus. Some have asserted his pretensions to the possession of the universal medicine, for he speaks of curing disease. But this seems a mere metaphorical expression, relating to transmutation. "Bring me," says he, "the six lepers, that I may cleanse them;" by which he doubtless would imply the conversion of silver, mercury, copper, iron, tin, and lead, into gold,—there being only these seven metals known at that period. Dr. Johnson supposes that the word *Gibberish*, anciently written *Geberish*, was originally applied to the language of Geber and his tribe.

ARTEPHIUS, in 1130, published several alchymical tracts; we are told by ROGER BACON and others, that he died at the advanced age of 1025, having prolonged his life by the miraculous virtues of his medicines; but his name, and that of JOHN DE RUPESCISSA, are now deservedly buried in oblivion.

The alchymical annals of the thirteenth century are adorned by the name of ROGER BACON, a native of Ilchester, in Somersetshire, and descended from an ancient and honourable family. In 1240, he returned from Paris, and became celebrated among the learned of the University of Oxford. At that time, however, the exposition of ignorance, and attempts to overthrow the dogmas of the schools, was a service of risk and danger ; and to this Friar BACON, for he was a monk of the Franciscan order, laid himself fully open : he was accused of practising witchcraft, thrown into prison, and nearly starved, for exposing the prevalent immorality of the clergy ; and, according to some, stood a chance of being burned as a magician.

I know of no work that strikes one with more surprise and admiration, than the *Opus Majus* of ROGER BACON ; he stands alone like a beacon upon a waste ; his expressions are perspicuous and comprehensive, such as betoken a rare and unclouded intellect ; and they are full of anticipations of the advantages likely to be derived from that mode of investigation insisted upon by his great successor, Chancellor BACON. This resemblance between ROGER BACON and his illustrious namesake has scarcely been noticed by the historians of his period ; it has, however, not escaped Mr. HALLAM's observation, who adverts to it in his *History of the Middle Ages.* Whether Lord BACON, he says, " ever read the *Opus Majus,* I know not ; but it is singular, that his favourite quaint expression, *prærogativæ scientiarum,* should be found in that work ; and whoever reads the sixth part of the *Opus Majus,* upon experimental science, must be struck by it as the prototype in spirit of the *Novum Organum.* The same sanguine and sometimes rash confidence in the effect of physical discoveries ; the same fondness for experiment ; the same preference of inductive to abstract reasoning, pervade both works."

The alchymical work of ROGER BACON that has been most prized, is the *Mirror of Alchymy*, but there is little either of interest or entertainment to be extracted from it.

ROGER BACON has by some been spoken of as a benefactor to mankind, by others as an enemy to the human race, inasmuch as he is plausibly considered to have invented gunpowder*, an invention by which the personal barbarity of warfare has certainly been diminished, " but which, considered as an instrument of human destruction, by far more powerful than any that skill had devised, or accident presented, before; acquiring, as experience shews us, a more sanguinary dominion in every succeeding age, and borrowing all the progressive resources of science and civilization for the extermination of mankind, appals us," says Mr. HALLAM, " at the future prospects of the species, and makes us feel, perhaps more than in any other instance, a difficulty in reconciling the mysterious dispensation with the benevolent order of Providence."

This discovery has sometimes been given to BARTHOLOMEW SCHWARTZ, a German monk, and the date of 1320 annexed to it, a date posterior to that which may be justly claimed for Friar BACON. Upon the authority, however, of an Arabic writer in the Escurial collection, referred to by Mr. HALLAM, there seems little reason to doubt that gunpowder was intro-

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* " From saltpetre and other ingredients," says Roger Bacon, " we are able to form a fire which will burn to any distance." And again, alluding to its effects, " a small portion of matter about the size of the thumb, *properly disposed*, will make a tremendous sound and corruscation, by which cities and armies might be destroyed." And again, in the same work, is a passage which, though somewhat enigmatical, is supposed to divulge the secret of this preparation. " Sed tamen salis petræ, *luru mone cap urbre*, et sulphuris, et sic facies tonitrum si scias artificium." The anagram is convertible into *carbonum pulvere*. Such are the claims of Roger Bacon to a discovery which soon changed the whole art of war.

The works of Bacon most deserving perusal are the *Opus Majus*, edited by Dr. Jebb in 1733; and his *Epistola de secretis Operibus Artis et Naturæ, et de nullitate Magiæ*. Paris, 1532. The former, addressed to Pope Clement IV., breathes sentiments which would do honour to the most refined periods of science.

duced, through the means of the Saracens, into Europe, before the middle of the fifteenth century, though its use in engines of war was probably more like that of fire-works than artillery. Many authorities might be adduced to prove the common use of gunpowder early in the fourteenth century. EDWARD III. employed artillery with memorable effect, at the battle of Cressy; and in the fifteenth century hand-cannons and muskets came into use, and gunpowder was in common employ.

ALBERT OF COLOGNE, surnamed THE GREAT, was a contemporary of ROGER BACON; he is celebrated as the inventor of the brazen head, which was demolished by the pious zeal of his pupil, the angelical Dr. AQUINAS, in consequence of his suspecting it to be an agent of the devil. ALBERTUS MAGNUS was what in our days is termed an universal genius. He is chiefly celebrated as the commentator of ARISTOTLE; but, if we give credit to contemporary writers, he was deeply skilled in all the higher departments of alchymical philosophy.

The names of RAYMOND LULLY, of Majorca, and ARNOLD of Villanova *, occur in this page of the history of chemical science. Their merit, however, consists rather in the quantity than quality of their writings. LULLY died on his passage from Africa in 1315, whither he had been to preach the truths of the Gospel; his body was carried to Majorca, where he was honoured as a martyr. BRUCKER says, "he was more ingenious than honest." His chemical opinions are scarcely worth quotation or abstract. He is said to have converted iron into gold in the presence of EDWARD I. in London, which was coined into rose-nobles †.

ARNOLD shines as a magician and astrologer. He was a renowned prophet, and predicted that the world would come

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* Raymond Lully was born in Majorca in 1236, and Arnold of Villanova in Provence in 1235.

† Bergman, *Histor. Chem.*

to an end in the year 1376. He was shipwrecked on the coast of Genoa, in 1313.

ISAAC and JOHN of Holland were also alchemical philosophers of this period *.

About the year 1560, a *Treatise of Alchymy* was published at Paris, attributed to NICHOLAS FLAMMEL. The work, however, is spurious, and was merely ascribed to him from his becoming suddenly, as it is said, very rich. The use he made of his wealth does his memory much credit: he founded hospitals, repaired churches, and endowed several charitable institutions; proceedings which by no means savour of alchymy.

Dr. SALMON, who in 1692 published one of the above-mentioned tracts, says, " FLAMMEL was originally a poor scrivener, yet left so great monuments behind him, as must convince the most incredulous that he knew the secret; and performed such mighty works at his own proper cost and charges, as the most opulent prince in Europe can never do the like. I know," says he, " a gentleman who went to view those mighty buildings and their records. The archives and governors of those places, he told me, own the matter of fact, but deny the means, saying, that FLAMMEL was a very pious man, and went a pilgrimage to St. James of Gallicia, for a reward of which piety the holy saint bestowed that vast treasure upon him by way of miracle; thereby denying the power of art by which it was certainly effected, to establish a miracle performed by the Romish saint."

He was moreover celebrated for his hieroglyphics, of which fac-similes are given in SALMON's edition. They are much of the same cast as those that now adorn MOORE's *Almanac*, and quite as edifying.

In SALMON's collection we find the *Marrow of Alchymy*,

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* " Sequuntur nunc Johannes et Isaacus Hollandus, pater et filius, qui diffusissimo sermone et magne eloquentiâ scripserunt, et si unum vel alterum arcanum exceperis pulcherrima experimenta fecerunt de sanguine et urinâ humanâ, quæ Helmontius postea et Boylæus pro recentioribus inventis habuerunt."—Boerhaave.

by George Ripley, *Chanon of Bridlington in Yorkshire*, who was a chemist perhaps less deserving of the reputation he acquired than most of his compeers. He may be quoted as a chemical poet. His *Compound of Alchemie*, dedicated to Edward IV., is rugged enough, but not unintelligible. The following stanzas from the preface of this piece, given in Ashmole's *Theatrum Chemicum Britannicum*, will afford a fair idea of Ripley's merits as a poet and philosopher :—

"But into Chapters thys Treatis I shall devyde,
In number twelve, with dew recapytulatyon;
Superfluous rehearsalls I lay asyde,
Intendyng only to give trew informatyon,
Both of the theoryke and practycall operatyon:
That by my wrytyng who so wyll guyded be,
Of hys intente perfyctly speed shall he.

"The fyrst chapter shall be of naturall *Calcination;*
The second of *Dyssolution*, secret and phylosophycall;
The third of our elementall *Separation ;*
The fourth of *Conjunction* matrimoniall;
The fyfth of *Putrefaction* then followe shall;
Of *Congelation Albyficative* shall be the sixt,
Then of *Cybation*, the seaventh shall follow next.

"The secret of our *Sublymation* the eyght shall show;
The nynth shall be of *Fermentatyon ;*
The tenth of our *Exaltation* I trow.
The elevent of our mervelose multiplycatyon,
The twelfth of *Projection*, then *Recapitulatyon*,
And so this treatise shall take an end,
By the help of God, as I entend.

"Thus here the Tract of Alchemie doth end ;
Which tract was by George Ripley, Chanon, penn'd.

It was composed, writt, and signed his owne,
In anno twice seaven hundred seaventy-one.
Reader, assist him, make it thy desire
That after lyfe he may have gentle fire!
Amen."

The degree of faith placed in alchymy was of course much shaken by the multiplied experiments that were undertaken during the seventeenth century ; in general, however, those who failed attributed their ill success to any rather than the real cause. Salmon's creed is that of most of his contemporaries. "As to the great and philosophic work," says he, (meaning transmutation,) "it is my opinion and belief that there is such a thing in nature. I know the matter of fact to be true, though the way and manner of doing it is as yet hid from me. I have been eye-witness of so much as is able to convince any man endued with rational faculties, that there is a possibility of the transmutation of metals; yet, for all these things, will not advise any man, ignorant of the power of nature and the way of operation, to attempt the work, lest, erring in the foundation, he should suffer loss and blame me. Without doubt it is a gift of God from above, and he that attains it must patiently wait the moving of the waters; when the destined angel moves the waters of the pool, then is the time to immerge the leprous metal, and cleanse it from all impurities."

VAN HELMONT says, "I am constrained to believe in the making of gold and silver, though I know many exquisite chemists to have consumed their own and other men's goods in search of this mystery; and to this day we see these worthy and simple labourers cunningly deluded by a diabolical crew of gold and silver sucking-flies and leaches. But I know that many will contradict this truth; one says it is the work of the devil, and another, that the sauce is dearer than the meat."

BERGMAN, in summing up the evidence for and against the possibility and probability of transmutation, and founding his opinion upon the multitude of relations that have been handed down to us by different writers of apparent veracity, one or two of which I shall presently quote, observes, that "although most of them are deceptive, and many uncertain, some bear such character and testimony, that unless we reject all historical evidence we must allow them entitled to confidence *." For my own part, the perusal of the histories of transmutation appears to me to furnish solid grounds for a diametrically opposite opinion. They are all of a most suspicious character;

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* *Opuscula,* IV. 127.

sometimes the fraud was open and intentional, seconded by juggling dexterity; at other times the performers deceived themselves; they purchased what was termed a *powder of projection*, prepared by the adepts, containing a portion of gold, and when they threw it into the fire with mercury, and found that portion of gold remaining in their crucible, they had not wit enough to detect its source: but the cases which are quoted as least exceptionable are often exactly those which are really impossible; I mean, where the weight of the powder of projection, and of the lead or other base metal taken conjointly, was exceeded by that of the gold produced. Such is HIERNES' history of PAYKUL's transmutation, who, with six drachms of lead and one of powder, produced an ingot that was coined into 147 ducats; and many others. But the most celebrated history of transmutation is that given by HELVETIUS in his *Brief of the Golden Calf: discovering the rarest Miracle in Nature, how by the smallest portion of the Philosophers Stone a great Piece of Common Lead was totally transmuted into the purest transplendent Gold, at the Hague in* 1666; and, as it is a luminous epitome of all that has been done on this subject, I shall briefly abridge the proceedings:—

" The 27th day of December 1666, in the afternoon, came a stranger to my house at the Hague, in a plebeick habit, of honest gravity and serious authority, of a mean stature and a little long face, black hair not at all curled, a beardless chin, and about 44 years (as I guess) of age, and born in North Holland. After salutation he beseeched me with great reverence to pardon his rude accesses, for he was a lover of the Pyrotechnian art, and having read my treatise against the sympathetic powder of Sir KENELM DIGBY, and observed my doubt about the philosophic mystery, induced him to ask me if I really was a disbeliever as to the existence of an universal medicine which would cure all diseases, unless the principal parts were perished or the predestinated time of death come. I replied, I never met with an adept, or saw such a medicine, though I had fervently prayed for it. Then I said, surely you are a learned physician. No, said he, I am a brass-founder, and a lover of chemistry. He then took from his bosom-pouch a neat ivory box, and out of it three ponderous lumps of stone, each about the bigness of a walnut. I greedily saw and handled for a quarter of an hour this most noble substance, the value of which might be somewhere about twenty tons of gold; and having drawn from the owner many rare secrets of its admirable effects, I returned him this treasure of treasures with a most sorrowful mind, humbly beseeching him to bestow a fragment of it upon me in perpetual memory of him, though but the size of a coriander seed. No, no, said he, that is not lawful: though thou wouldest give me as many golden ducats as would fill this room; for it would have particular consequences, and if fire could be burned of fire, I would at this instant rather cast it all into the fiercest flames. He then asked if I had a private chamber whose prospect was from the public street; so I presently conducted him to my best furnished room backwards, which he entered," says HELVETIUS, (in the true spirit of Dutch cleanliness,) "without wiping his shoes, which were full of snow and dirt. I now expected he would bestow some great secret upon me, but in vain. He asked for a piece of gold, and opening his doublet showed me five pieces of that precious metal which he wore upon a green riband, and which very much excelled mine in flexibility and colour, each being the size of a small trencher. I now earnestly again craved a crumb of the stone, and at last, out of his philosophical commiseration, he gave me a morsel as large as a rape-seed; but I said, this scanty portion will scarcely transmute four grains of lead. Then, said he, deliver it me back: which I did, in hopes of a greater parcel; but he cutting off half with his nail, said, even this is sufficient for thee. Sir, said I, with a dejected countenance, what means this? And he said, even that will transmute half an ounce of lead. So I gave him great thanks, and said I would try it, and reveal it to no one. He then took his leave, and said he would call again next morning at nine. I then confessed that while the mass of his medicine was in my hand the day before, I had secretly scraped off a bit with my nail, which I projected on lead, but it caused no transmutation, for the whole flew away in fumes. Friend, said he, thou art more dexterous in committing theft than in applying medicine; hadst thou wrapt up thy stolen prey in yellow wax, it would have penetrated and transmuted the lead into gold. I then asked if the philosophic work cost much or required long time, for philosophers say that nine or ten months are required for it. He answered, their writings are only to be understood by the adepts, without whom no student can prepare this magistery. Fling not away, therefore, thy money and goods in hunting out this art, for thou shalt never find it. To which I replied, As thy master showed it thee, so mayest thou perchance discover something thereof to me, who know the rudiments, and therefore it may be easier to add to a foundation than begin anew. In this art, said he, it is quite otherwise; for unless thou knowest the thing from head to heel, thou canst not break open the glassy seal of HERMES. But enough; to-morrow, at the ninth hour, I will show thee the manner of projection. But ELIAS never came again; so my wife, who was curious in the art whereof the worthy man had discoursed, teazed me to make the experiment with the little spark of bounty the artist had left me; so I melted half an ounce of lead, upon which my wife put in the said medicine; it hissed and bubbled, and in a quarter of an hour the mass of lead was transmuted into fine gold, at which we were exceedingly amazed. I took it to the goldsmith, who judged it most excellent, and willingly offered fifty florins for each ounce." Such is the celebrated history of ELIAS THE ARTIST and Dr. HELVETIUS.

SIR KENELM DIGBY, whose name is mentioned in this narrative, was a renowned dabbler in the mysterious art. Under the date of seventh November, 1651, in EVELYN'S

*Diary**, "he gave me," says Mr. EVELYN, "a certain powder, with which he affirmed that he had fixed mercury before the late king. He advised me to try and digest a little better, and gave me a water which he said was only rain-water, of the autumnal equinox, exceedingly rectified and very volatile: it had a taste of strong vitriolic, and smelt like aquafortis. He intended it for a dissolvent of calx of gold; but the truth is, Sir KENELM was an arrant mountebank."

Nearly all the alchymists attributed the power of prolonging life either to the philosopher's stone, or to certain preparations of gold, imagining possibly that the permanence of that metal might be transferred to the human system. The celebrated DESCARTES is said to have supported such opinions; he told Sir KENELM DIGBY, that although he would not venture to promise immortality, he was certain that life might be lengthened to the period of that of the Patriarchs. His plan, however, seems to have been the very rational one of limiting all excess of diet, and enjoining punctual and frugal meals†.

The history of alchymy has been greatly enriched by the labours of the celebrated ELIAS ASHMOLE, who in 1652 published his *Theatrum Chemicum Britannicum, containing several Poeticall Pieces of our famous English Philosophers, who have written the Hermetique Mysteries in their owne ancient Language.*

The most remarkable piece in this collection is the *Ordinall of Alchimy, by* THOMAS NORTON, illustrated by several comical cuts. It treats, in separate chapters, of the objects of the occult science; of the difficulties of attaining them; of the different methods of pursuing them; of the characters of the elements; and of the five concords, of which the first is *Patience*, the second *Assistance*, the third *Instruments*, the fourth *Situation*, and the fifth *Planetary Influence*. It is difficult to select from this production any specimen capable of conveying an idea of its merits, that can come within the limits of a quota-

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* BRAY'S *Memoirs of John Evelyn.*

† See *Life of Descartes*. CHALMERS'S *Biographical Dictionary*.

tion. Perhaps the following lines, picked out of the seventh chapter, touching "the Regiment of Fiers," may serve to convey some idea of the author's talents in the double capacity of poet and philosopher.

> "In many authors written you may see,
> *Totum consistit in ignis regimine;*
> Wherefore in all things so proceed,
> That heat work no more no less than it need;
> Wherein many of Geber's cooks
> Deceived were, though they be wise in books.
> Such heate wherewith a pig or goose is scalded
> In this arte *Decoction* it is called;
> Such heate as dryeth lawne karchiefs fair,
> In thirty operations serveth for our ayre;
> But for divisions you must use such heate,
> As cook's make when they roaste raw meate.
> *Ignis humidus* another fier alsoe
> Is, and yet seemeth *oppositum in adjecto:*
> Another fier is fier of desiccation,
> For matters which be imbibed with humectation.
> *Ignis corrodens* serveth in this arte,
> *Elementa propinqua* wisely to depart.
> By one point of excess all your work is shent,
> And one point too little is insufficient;
> Who can be sure to find its trew degree,
> *Magister magnus in igne* shall he be.
> All that hath pleasure in this booke to reade,
> Pray for my soule, and all both quick and deade.
> In this year of Christ 1477,
> This work was begun, honour to God in heaven."

In later times we have had two or three believers in transmutation. In the year 1782, Dr. Price, of Guildford, by means of a white and red powder, professed to convert mercury into silver and gold, and is said to have convinced many disbelievers of the possibility of such change; his experiments were to have been repeated before an adequate tribunal, but he put a period to his existence by swallowing laurel-water.

Another true believer in the mysteries of this art was Peter Woulfe, of whom it is to be regretted that no biographical memoir has been preserved. I have picked up a few anecdotes respecting him from two or three friends who were his acquaintance. He occupied chambers in Barnard's Inn while residing in London, and usually spent the summer in Paris. His rooms, which were extensive, were so filled with furnaces and apparatus that it was difficult to reach his fire-side. A friend told me, that he once put down his hat, and never could find it again, such was the confusion of boxes, packages, and parcels, that lay about the chamber. His breakfast hour was four in the morning; a few of his select friends were occasionally invited to this repast, to whom a secret signal was given by which they gained entrance, knocking a certain number of times at the inner door of his apartment. He had long vainly searched for the elixir, and attributed his repeated failures to the want of due preparation by pious and charitable acts. I understand that some of his apparatus is still extant, upon which are supplications for success, and for the welfare of the adepts. Whenever he wished to break an acquaintance, or felt himself offended, he resented the supposed injury by sending a present to the offender, and never seeing him afterwards. These presents were sometimes of a curious description, and consisted usually of some expensive chemical product or preparation. He had an heroic remedy for illness: when he felt himself seriously indisposed, he took a place in the Edinburgh mail, and having reached that city, immediately came back in the returning coach to London. A cold taken on one of these expeditions terminated in an inflammation of the lungs, of which he died in 1805. He is the author of several papers in the *Philosophical Transactions*.

A few other persons of less note might be quoted as believers in transmutation, but the history of one is that of all; and, in the emphatic language of Spenser, they were doomed

> "To lose good days that might be better spent,
> To waste long nights in pensive discontent;
> To speed to-day, to be put back to-morrow,
> To feed on hope, to pine with fear and sorrow;
> To fret their souls with crosses and with cares,
> To eat their hearts through comfortless despairs:
> Unhappy wights! born to disastrous end,
> That do their lives in tedious tendance spend."

But although the alchymists have given us little in the way of useful facts or applicable discoveries, their reign was fruitful in the invention of apparatus. Alembics, stills, retorts, receivers, and a variety of whimsical and complex vessels, in glass and porcelain, are described and depicted in their works; and they not only possessed all the furnaces with which our modern laboratories are necessarily supplied, but were particularly expert in their construction, and often surprisingly happy in their application.

§ II.

There are many points in alchemical history which have been purposely passed over, as affording nothing worthy of remark, and as suggesting nothing that throws light upon the brighter ages of chemistry. It has been too common to load the alchymists with honours which they ill deserve: the picture of their proceedings, already given, is as correct and faithful as the materials that compose it admit of; and it presents nothing that the mind rests upon with satisfaction; nothing that it reverts to with interest or profit. But there were contemporaries with the alchymists, whose pursuits were conducted upon more rational principles, and whose writings, though often overshadowed by the clouds of magic and astrology, are, in many instances, illumined by rays of sober experimental investigation; they often indulge in the insane caprices of the mere searchers for the philosopher's stone, but their madness has method in it, and their wanderings are not without a plan.

Of these persons, the first that I shall select as worthy notice, is Basil Valentine, of Erfurth, who wrote about the middle of the fifteenth century, and who may justly be considered as one of the founders of modern chemistry: his experiments always had an object, and he details them with intelligible perspicuity; it is true that he often launches into the sea of alchymy, but he returns unpolluted by its follies: where he speaks as an adept, he is as absurd as need be; but, as the narrator of experiments, he abounds in shrewd remarks, and was uncommonly successful in his pursuits. The extant works of Basil Valentine are not very numerous, and they have mostly become extremely scarce. In 1671, his *Triumphant Chariot of Antimony* was republished at Amsterdam, from the original edition of 1624, with copious notes by Dr. Theodore Kirkringius; and a few years after, an English translation of that celebrated production was printed at London. In 1644, his *Haliographia* appeared at Bologna. This work treats of the preparation, uses, and virtues of mineral, animal, and vegetable salts, and is a curious and well digested body of information upon a variety of chemical subjects. These are the only works of Basil Valentine that I have been able to meet with, and I believe they contain the pith of his chemical knowledge. In both these works, he appears in the double capacity of chemist and physician. In physic he was a brave champion for the chemical sect, and his *Triumphant Chariot of Antimony*, especially, abounds in reflections, not of the mildest description, upon the practice and theories of his adversaries,—whom he despises, because, unable to prepare their own medicines, "they know not whether they be hot or dry; black or white; they only know them as written in their books, and seek after nothing but money. Labour is tedious to them, and they commit all to chance; they have no conscience, and coals are outlandish wares with them; they write long scrolls of prescriptions, and the apothecary thumps their medicine in his mortar, and health out of the patient."

But when we find many most important facts recorded in the pages of this writer, we shall readily excuse the irrelevant matter by which they are accompanied; and, in this view, his writings deserve the attentive perusal of those who would trace modern improvements to their parent inventions and discoveries, and these to their more remote and recondite sources. To say nothing of the numerous and truly important preparations of antimony with which Basil Valentine enriched the *Materia Medica*, and of which he has given an intelligible and copious account in the *Currus Triumphalis*, we find in his works the first accurate mention of, and intelligible directions for the preparation of nitric, muriatic, and sulphuric acids; and were these his only contributions to the laboratory, I need hardly say how richly he merits the eulogies of the moderns, when we reflect upon the numerous uses to which those acids are now applied, upon their importance in several of the most refined and extensive branches of art, and upon the advances in technical and scientific chemistry which have been attained by their aid.

In order to obtain the *water of nitre*, for by that name he designates the acid, Valentine directs us to distil three parts of powdered earthenware with one of nitre. The mixture is to be subjected in a proper earthen alembic to a red heat, and a capacious receiver annexed. Now, this process is, in many countries, still practised, and, although neither convenient, nor, generally speaking, economical, the acid it affords is sufficiently pure. The opinion of the old chemists, respecting this production of nitric acid, was, that the clay held down the nitre so as to expose it to the searching influence of the fire; but the decomposition depends upon the attraction of the potassa of the nitre for the ingredients of the clay, a kind of red slag remaining in the retort.

Another mode of procuring nitric acid mentioned by this writer, though probably of more ancient date, since Raymond Lully seems to have known it, comes much nearer to the process now in common use, and may, in many situations, be conveniently and economically practised. It consists in distilling equal parts of nitre and dried green vitriol. The residue consists of sulphate of potassa and oxide of iron; the former may be separated by washing with hot water, and an oxide of iron, of a deep red colour, remains, used by the polishers of plate-glass, under the name of *colcothar*.

Under the directions for preparing the salt of gold in the *Haliographia*, I find a third mode suggested for the production of acid from nitre, which consists in distilling saltpetre with finely-pounded flints. It depends upon the attraction of siliceous earth for potash, which combine to form a glassy slag.

Such are the facts which are recorded by BASIL VALENTINE respecting the preparation of nitric acid; he termed it *water*, or *acid spirit* of nitre. It was afterwards called *aquafortis*, and its property of dissolving gold, with the addition of sal ammoniac, or of muriatic acid, is often adverted to and descanted upon by the same author.

For nearly two hundred years after the discovery of *aquafortis*, its chemical history was but little advanced; nor, indeed, were any facts of importance respecting its true nature made out, until Dr. PRIESTLEY and Mr. CAVENDISH commenced their researches, about the middle of the last century.

The method which, in this country, is now universally resorted to for the production of *aquafortis*, consists in the decomposition of nitre by sulphuric acid; the results are liquid nitric acid, and sulphate of potassa.

Dr. PRIESTLEY *, between 1774 and 1778, made a variety of curious experiments to ascertain the effects of heat on nitric acid: he passed it through a red-hot tube, and found it resolved into oxygen, nitrous gas, nitrous vapour, and water; and thus the composition of this acid was analytically demonstrated. About the same time, Mr. CAVENDISH † produced this acid, by passing repeated electrical explosions through

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* Dr. Priestley on Air, vol. iv. p. 3.

† Phil. Trans. vols. lxxv. and lxxviii.

common air, and through mixtures of oxygen and nitrogen, over solution of potassa.

Thus the nature of nitric acid was synthetically and analytically demonstrated; and from the result of the most accurate and recent experiments upon this subject, it appears to consist, in its dry and combined state, of 14 nitrogen + 40 oxygen; and in the liquid state, of 54 dry acid + 18 water.

But the discovery of nitric acid is certainly second in importance to that of oil of vitriol, or, as it is now called, *sulphuric acid*, the honour of which is also due to Basil Valentine; for it is not, as far as my information goes, described in any earlier writer: he frequently mentions it, and the mode of its preparation; and Paracelsus, and the authors who immediately followed, talk of it as well known, and in common use, though it is probable that it bore a high price, and was but scantily supplied by a few awkward and unintelligent operators.

In the *Currus Triumphalis*, the spirit afforded by the distillation of vitriol is not unfrequently adverted to, and its action upon certain antimonial compounds so fully described, as to leave no doubt respecting its nature. In the *Haliographia*, however, *oil of vitriol* is distinctly mentioned; and, what is curious, we find in the chapter of that tract relating to the extraction of the salts of iron, particular directions for the preparation of sulphat of iron, by dissolving iron filings in a mixture of one part of oil of vitriol, and two of water: this solution, he says, "when put aside in a cool place, soon forms beautiful crystals;" and in another section we are told, that "this salt is an excellent tonic; that it comforts weak stomachs; and that externally applied, it is an admirable styptic." And this, in fact, is nearly all that we can say of the preparation and medical uses of this salt of iron at the present day.

The mode of obtaining sulphuric acid, by the distillation of sulphate of iron, or green vitriol, is still extensively practised upon the Continent, in Germany, Sweden, and more especially at Bleyl, in Bohemia*. The vitriol is first deprived of water of crystallization, and then submitted, in glass retorts coated with clay, to a red heat; white fumes pass over into the receivers, which become very hot during the condensation of these fumes into an unctuous reddish-brown fluid, which, from its viscidity and appearance, acquired the name of *oil* of vitriol: there remains in the vessels a substance of a fine red colour, which, when washed and levigated, furnishes what has been termed *colcothar*, or *caput mortuum* of vitriol; for the old chemists were in the habit of representing the dregs and last products of substances by the symbol of a death's head and cross bones.

The oil of vitriol, thus prepared, exhales fumes when exposed to a moist atmosphere, and occasionally congeals or crystallizes; circumstances which led to its name of *glacial oil of vitriol*, and which show that it differs from the acid as ordinarily prepared. It is, in fact, the anhydrous acid.

That sulphur during combustion produces a portion of acid water, seems to have been known at a very early period; but the method of obtaining sulphuric acid by burning a mixture of sulphur and nitre is, I believe, first described by VALENTINE in his *Chariot of Antimony*, under the name of oil of antimony, for he employed sulphuret of antimony for its production. The original recipe runs thus:—

"Take of antimony, sulphur, saltnitre, of each equal parts, fulminate them under a bell, as oil of sulphur, *per campanam*, is made, which way of preparing hath long since been known to the ancients; but you will have a better way if instead of a bell you take an alembic, and apply to it a recipient; so you will obtain more oil, which will indeed be of the same colour as that made of common sulphur, but in powers and virtues not a little more excellent."

Dr. WARD, the inventor of many celebrated nostrums, was

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* Aikin's Dictionary, art. *Sulphuric Acid.*

the first person who brought this preparation into notice in England; and he obtained a patent for his invention, and for a considerable time monopolized the manufacture of the acid. At length Dr. ROEBUCK, an eminent physician of Birmingham, substituted an apparatus of lead for the glass vessels previously used. This was in 1746, since which the price of sulphuric acid has been greatly reduced, and the manufacturer consequently enabled to employ it for a variety of purposes, to which it was previously inapplicable, from its scarcity and high price. In 1772, the first manufactory of sulphuric acid near the metropolis, was established by Messrs. KINGSCOTE and WALKER, at Battersea*.

I have mentioned that the necessity and advantages of nitre, as an addition to sulphur in increasing the acid product, was known to VALENTINE; but the manner in which it operates is a later discovery. As the expense of the operation is increased by it, many attempts have been made to supersede its use by the employment of other materials, under the impression that it merely furnished oxygen; but a little reflection easily proves the fallacy of such a notion; for, even if we burn sulphur in pure oxygen, sulphurous, and not sulphuric acid, is the result. The solution of this chemical problem has been chiefly effected by the researches of Sir H. DAVY, who has proved that the products of the nitre are concerned in transferring oxygen to the sulphur. A patent has more lately been taken out for a mode of preparing sulphuric acid by the combustion of pyrites, without the intervention of nitre, but its success is doubtful.

The numerous antimonial preparations described in the *Chariot of Antimony* deserve more notice than they have generally received from the chemical historian; and the perusal of that work affords some insight into the celebrated disputes between the galenical and chemical physicians, which were afterwards pushed so far by PARACELSUS.

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* Parkes, Chemical Essays, vol. ii. p. 388.

Basil Valentine, adverting to the notion that antimony* was poisonous, tells us, that its noxious qualities may not only be subdued by art, but that various properties may be communicated to its different preparations—"As a blacksmith," he says, "with one sort of fire, and iron only is his matter, of which he forms divers instruments. Sometimes he makes a spit, at another time horse-shoes, another time a saw, and at length innumerable other things, every of which serves for that use for which the smith intended it. So of antimony various works may be made for different uses,—in which the artist is the smith that forms, Vulcan is the key which opens, and operation and utility give experience and knowledge of the use. Oh, if foolish and vain men would hear and understand what I write, they would not suck their turbid and insalubrious potions, but hasten to these limpid fountains, and drink of the well of life."

In pursuing his defence of antimony, the author allows its venomous nature, but then tells us, that upon that circumstance its value in medicine depends, upon the principle that venom draws venom to itself; and adduces as proof of this position, the well-known fact, as he terms it, that a dried toad reduced to powder, and sprinkled upon the wound occasioned by a viper's bite, cures it.

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* It is probable that the word Antimony was first used by Basil Valentine. Tradition relates, that having thrown some of it to the hogs, after it had purged them heartily, they immediately fattened; and, therefore, he imagined, that his fellow monks would be the better for a like dose, they having become lean by fasting and mortification. The experiment, however, failed, and they died; whence the medicine was called *Anti-moine.*

§ III.

Paracelsus comes next in chronological order to his predecessor, Basil Valentine, but as a chemist he falls far short of that master; his original discoveries are few and unimportant, and his great merit lies in the boldness and assiduity which he displayed in introducing chemical preparations into the *Materia Medica*, and in subduing the prejudices of the galenical physicians against the productions of the laboratory. The principal events of his life are the following:—His real name was Philip Hochener, which he changed, on commencing his professional career, into Theophrastus Bombastus Paracelsus *. At an early age he visited the most renowned towns in Europe, and returning to his native country, was made professor of medicine and chemistry at Basle; he availed himself of this public situation, not to instruct the unlearned, but to vilify his contemporaries and predecessors. It is generally said, that his dissolute manners and intractable temper obliged him to quit his occupation. But others have told a more plausible story: a rich Canon fell sick, and getting frightened, offered 100 florins to any one who would cure him. Paracelsus administered three pills, and the Canon got well; but being so soon restored, and by such simple means, he refused to fulfil his promise. The matter was brought before a magistrate, who decreed that the doctor should only recover the customary fee. Irritated at the flimsy excuses and unpardonable ingratitude of the priest, and at the magistrate's partial decision, Paracelsus declared that he

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* "Hunc virum," says Boerhaave, "alii coluerunt pro Deo, imo locutus sum cum hominibus qui credunt eum non esse mortuum, sed vivum sedere in sepulchro pertæsum peccatorum et malorum hominum." The following is an illustrative anecdote of his impudence: "Cum adscenderet Cathedram physico medicam, sumsit vas æneum cum igne, immisit sulphur et nitrum, et simul Galenum, Avicennam, et Arabes conjecit in ignem, dicens, sic vos ardeditis in gehennâ."

would leave the inhabitants of Basle to the eternal destruction which they deserved; he then retired to Strasburgh, and thence into Hungary, where he took to drinking, and died in great poverty at Saltzburgh, in 1541, and in the forty-third year of his age. Though we can fix upon no particular discovery on which to found his merits as a chemist,—and though his writings are deficient in the acumen and knowledge displayed by several of his contemporaries and immediate successors, especially by THEODORE DE MAYERNE, and DU CHESNE, or, ashe was generally called, QUERCITANUS,—it is undeniable that he gave a most important turn to pharmaceutical chemistry; and calomel, first described by CROLLIUS in 1609, with a variety of mercurial and antimonial preparations, as likewise opium, came into general use. Although the chemical physicians, however, were very successful, they were aware of the unpopularity of their means; people were frightened at the idea of mercury and antimony, which were accordingly exhibited under fantastic and assumed names. Towards the end of the fifteenth century, the use of antimony was prohibited at Paris; and BESNIER expelled the faculty for having persevered in administering it. In England, chemical medicines began to be employed in the reign of Charles I. In 1644, SCHRÖDER published his *Chemico-Medical Pharmacopœia;* and shortly after that of the London College made its appearance; but although the history of pharmaceutical chemistry must not be blended with the abstract progress of the science, yet should it not be forgotten, that the great modern improvements in chemistry have sprung from its applications to medicine, and that the foundations of chemical science are to be found in the medical and pharmaceutical writers of the sixteenth century, who rescued it from the hands of the alchemical pretenders, and gave it a place and character of its own.

The enthusiastic ravings of PARACELSUS tended to awaken the more solid talents of VAN HELMONT of Brussels, who flourished in the early part of the seventeenth century, and who studied and admired the works of his less modest predecessor. VAN HELMONT has left a curious memoir containing a sketch of his own life, and exhibiting the various circumstances that gave an impulse to his proceedings, and the different causes that suggested his pursuits. In this biographical relic, there is a vein of sound and unaffected argument, which displays a very amiable turn of mind in the writer. It would, however, be irrelevant to my present subject to give more than a very brief abstract, illustrative of the style and pursuits of the author. "In 1594, being then seventeen years of age, I finished my courses of philosophy; but upon seeing none admitted to examinations at Louvain who were not in a gown and hood, as though the garment made the man, I was struck with the mockery of taking degrees in arts. I therefore thought it more profitable seriously and conscientiously to examine myself; and then I perceived that I really knew nothing, or, at least, nothing that was worth knowing. I had, in fact, merely learned to talk and to wrangle, and therefore refused the title of Master of Arts, finding that nothing was sound, nothing true, and unwilling to be declared master of the seven arts, when my conscience told me I knew not one. The Jesuits, who then taught philosophy at Louvain, expounded to me the disquisitions and secrets of magic; but these were empty and unprofitable conceits; and, instead of grain, I reaped stubble. In moral philosophy, when I expected to grasp the quintessence of truth, the empty and swollen bubble snapped in my hands. I then turned my thoughts to medicine, and having seriously read GALEN and HIPPOCRATES, noted all that seemed certain and incontrovertible; but was dismayed upon revising my notes, when I found that the pains I had bestowed, and the years I had spent, were altogether fruitless; but I learned at least the emptiness of books and formal discourses and promises of the schools. I went abroad, and there I found the same sluggishness in study, the same blind obedience to the doctrines of their forefathers, the same deep-rooted ignorance *."

VAN HELMONT was called by his contemporaries an insane enthusiast ; but there is, even in the very imperfectly translated and brief quotation that I have taken from the history of his studies, a propitious gleam of that dawn of improvement which was diffused over science by the genius of Lord BACON.

The doctrine of the chemical elements was in full vogue during the time of VAN HELMONT, PARACELSUS, and VALENTINE, and salt, sulphur, and mercury, are unequivocally mentioned as the ultimate component parts of almost all the forms of matter. In the writings of VAN HELMONT, there are sundry allusions to the existence of aëriform bodies, and the word *gas*, now in common use, and applied to all aëriform matters differing from atmospheric air, first occurs in his pages: he also distinguishes between condensible gases or vapours, and incondensible or permanently elastic fluids; and under the term *gas silvestre*, he seems to comprehend what was afterwards called *fixed air*. As to the general tenour of his writings, it is difficult to separate the chemistry from the miscellaneous matters, and more especially from the medical commentaries with which it is blended ; but they abound in hints and observations, which, if not original, are at least ingenious and acute. In his experiments on air, he seems to have argued very plausibly on its weight and elasticity; and has detailed with much precision the effect of temperature and pressure, in his description of the air thermometer.

Entering upon the seventeenth century, the historian of Experimental Science must ever pause to pay a tribute of gratitude and respect to the celebrated FRANCIS BACON; a man whose faults as a statesman have been eclipsed to the

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* Johannis Baptistæ Van Helmont Opera omnia. Hafn. 1707. The above extract is from the Studia Authoris, p. 16.

eyes of posterity, by the brilliancy and excellence of his philosophical character.

It may commonly be observed, that those who are gifted by nature with superior genius or uncommon capacity, who are destined to reach the meridian of science, or to attain exalted stations in the learned professions, have exhibited early symptoms of future greatness: either indefatigable industry, or extraordinary sagacity, or ardent enthusiasm, have marked their entrance into the affairs of life. At the age of sixteen, BACON was distinguished at Cambridge; and, very shortly afterwards, struck with the frivolous subtilty of the tenets of ARISTOTLE, he appears to have turned his mind into that channel which led on to future eminence. The solid foundation of his scientific character is the *Instauration of the Sciences.* It opens with a general and philosophical survey of the subject; whence he proceeds to infer the futility of the ancient philosophical systems, and to point out Induction, from sober and severe experiments, as the only road to truth. Pursue this, he says, and we shall obtain new powers over nature; we shall perform works as much greater than were supposed practicable by natural magic, as the real actions of a Cæsar surpassed the fictitious ones of a hero of romance.

Speculative philosophy he likens to the lark, who brings no returns from his elevated flights; experimental philosophy to the falcon, who soars as high, and returns the possessor of his prey.

Illustrations of the new method of philosophizing, and the mode of arranging results, conclude this admirable and unrivalled performance.

To do justice to this work, we must, for a moment, forget the present healthy and vigorous constitution of science, and view it deformed and sickly in the reign of Elizabeth. We shall then not be surprised at the irrelative observations and credulous details which occasionally blemish this masterly production of the human mind.

But the history of Lord BACON furnishes other materials for reflection. Upon the accession of JAMES I., he became successively possessed of the highest honours of the law, and acquired great celebrity as a public speaker and a man of business; yet, amidst the harassing duties of his laborious avocations, he still found time to cultivate and adorn the paths of science, the pursuit of which furnished employment for his scanty leisure and relaxation in his professional toils; and, when ultimately disgraced, "his genius, yet unbroken, supported itself amidst involved circumstances and a depressed spirit, and shone out in literary productions." Nor should the munificence of his royal master remain unmentioned, who, after remitting his fine, and releasing him from his prison in the Tower, conferred upon him a large pension, and used every expedient to alleviate the burden of his age, and to blunt the poignancy of his sufferings.

After the death of Lord BACON, which happened in April 1626, in the 66th year of his age, the records of science begin to assume a brighter aspect; and we discern true knowledge emerging from the dungeons of scholastic controversy, and shaking off the shackles of polemical learning.

The middle of the seventeenth century was a period extremely fertile in chemical productions. In taking, however, a comprehensive view of the writers of this age, there are a few only whose labours deserve to be recorded as connected with the advancement of chemical knowledge; that is, as having contributed by new views and discoveries to the progress of what may be termed the philosophy of the science. They were generally mere recorders of insulated facts, or publishers of ill-digested and imperfectly arranged catalogues of the various preparations that were used in the arts, and in medicine; for the dread in which chemical preparations were viewed by physicians began now to decline; the *Materia Medica* was filled with new and more convenient forms, and the *Pharmacopœiæ* published under the authority of different governments, were allowed to divulge the preparation of calomel, emetic tartar, and several other highly important and useful compounds.

Among the writers of this period there is no one more rich in facts, and original in invention, than GLAUBER of Amsterdam. KUNCKEL was a successful promoter of chemistry applied to the arts; he wrote on the production of phosphorus, and on the art of glass-making, and was a favourite at many courts of Europe, more especially with Charles XI. of Sweden, who, in 1693, granted him letters of nobility. In 1673, LEMERY, the elder, conferred much service on chemistry by his dexterity as an experimentalist, and by the plain, perspicuous style in which he publicly taught the rudiments of the science. The discovery of phosphorus belongs also to this period, and although of little interest perhaps in the abstract, it drew a host of inquirers into the precincts of the laboratory, and was productive of more extensive and important consequences than have generally been attributed to it.

But having perused such of these writers as I have been able to procure, there is no one for whom I can so confidently ask attention as GLAUBER: he was not a mere maker of experiments, but he reasoned sensibly and even acutely upon their results; he occasionally oversteps the bounds of modest argument, deprecates the views of his contemporaries, and praises himself beyond all measure; but this vitiated style was then in fashion, and unlike most of his contemporaries, he has very sufficient claims to originality of invention. His works were translated into English, and published, as the title runs, "for public good, by the labour, care, and charge of CHRISTOPHER PACKE, *Phylo-Chemico-Medicus*, in 1689."

GLAUBER was so laborious an experimentalist, and in his experiments there is so much originality, that it is difficult to select those which can strictly be called discoveries, and upon which his scientific character deserves chiefly to be founded.

The distillation of volatile alkali from bones, and its conversion into sal ammoniac by the affusion of spirit of salt; the preparation of sulphate of ammonia, which he calls *secret sal ammoniac*, and its conversion into common sal ammoniac by distillation with common salt; the production of blue vitriol by the action of acid of vitriol upon the green rust of copper; the distillation of vinegar from wood, and the formation of a variety of salts useful in medicine and the arts by its action upon alkaline, earthy, and metallic substances; the distillation of muriatic acid, or spirit of salt, from a mixture of common salt and acid of vitriol; and the extraction of sulphate of soda, or *sal mirabile*, from the residue of this experiment, are a few, and only a very few, of the truly important inventions and discoveries that crowd upon us in the perusal of the verbose pages of GLAUBER. Of these the production of vinegar of wood, and of muriatic acid, may perhaps be regarded as of the greatest interest and importance.

The acid liquor produced during the destructive distillation of wood has lately become a manufacture of much importance, and is largely prepared by the makers of gunpowder, who obtain it as a result of their process for procuring charcoal.

GLAUBER describes the distillatory apparatus, which he calls "a press for extracting the juice of wood;" he shews its condensation into an acid liquor; and directs the method of burning lime, by ranging layers of chalk alternately with those of the wood. He also says, that by rectifying this spirit, "a sharp hot oil, of a dark reddish colour remains, and the *vinegar* passes over, fit for the preparation of medicines, and all other uses to which common vinegar is applicable." The oil, he adds, is an admirable preservative of wood, and when saponified with alkali, forms a most valuable manure; "a hogshead of which may be carried into fields and vineyards far remote, more easily than ten loads of common manure, which is carried to vineyards in rocky places with great difficulty. As to the spirit, physicians may use this noble and efficacious juice with great honour and profit in the cure of many diseases hitherto incurable;" and he highly extols an acid bath, made by due admixture of the vinegar of wood with warm water: he also shows the mode of concentrating it by exposure to cold, when "the phlegm only freezeth, but the sharp spirit remaineth in the middle of the hogshead, so sharp that it corrodeth metals like aqua fortis." After many other shrewd and clever remarks respecting the tar of wood and its acid, GLAUBER closes his discourse, fearing that it will not be believed by many, which, he says, he cannot help; "it contenteth me that I have written the truth, and lighted a candle to my neighbours."

The preparation of muriatic acid, as now commonly conducted, was first devised by GLAUBER; he obtained it by distilling common salt with acid of vitriol, and gives a sufficiently clear account of the nature of the chemical change that ensues. The residue of this operation retains to this day the name of GLAUBER's salt; or, as he termed it, *sal mirabile.* Upon its virtues he has descanted at great length, and though, in his history of this salt, its value and uses are preposterously exaggerated, his observations serve to shew the diligence and acuteness with which he investigated its applications, and offer proofs of the extensive information which he possessed relative to many processes of agriculture and the arts. Salt, in short, was GLAUBER's favourite element: "It is," says he, "the beginning and the end of all things, and it increaseth and exalteth their powers and virtues: it is the true universal medicine; not that I would have any man persuade himself, that in these words I would assert immortality, for my purpose tendeth not thither, seeing that I am not ignorant there is no medicine against death." And then, adverting to the opposition to chemical medicines by contemporary physicians, he advises them not to envy those "who have received such divine gifts as his wonderful salt, nor to provoke the innocent with their filthy calumnies and slanders, but to leave those things which exceed their capacities. Nothing," he says, "can extinguish truth; it may be prest, but cannot be overcome; like the sun's light it may be hidden, but not extinguished."

The directions he gives for the preparation of the *sal mirabile*, and the account of its properties, are in general very correct. "Its colour ought to be white and transparent; its figure is in long striæ or crystals; its taste is like ice melting upon the tongue, and yields some bitterishness. Being dried in the fire, and all the moisture gone off, it will lose about three parts of its own body, and retain a fourth part only; being dissolved in water, it will recover those three parts again. But, on the contrary, if it shoot into a square figure, and hath as yet a saltish taste, and being dried, loseth but little of its weight, it is not worth a rush, and shows that either the oil of vitriol was not good, or not enough of it used in the operation. These things we would not bury in silence, that so we might well advise young beginners, and withdraw them from their errors."

The present mode of preparing muriatic acid is almost exactly that devised by GLAUBER. In its pure state it was first obtained and examined by Dr. PRIESTLEY. The composition of this acid is a discovery of more modern date. The investigation which led to it was commenced by SCHEELE, and perfected by our contemporaries, GAY LUSSAC, and DAVY.

GLAUBER has great merit as an inventor and improver of chemical apparatus, much of which is depicted in the plates attached to his works. The form of distillatory vessels, commonly called WOULFE'S apparatus, is found in GLAUBER'S *Chemical Furnaces;* and he contrived a very ingenious mode of heating large vessels of water by steam, and with great economy of fuel, — a method now often resorted to.

He published a pamphlet, entitled, *The Consolation of Navigators, in which is taught how they who travel by Sea may preserve themselves from Hunger and Thirst; and also from those Diseases which are wont to happen in long Voyages. Written for the Health, Comfort, and Solace, of all those who travel by Water for the good of their Country.* The very sensible plan of employing extract of malt as a portable vegetable diet, and dilute muriatic acid to quench thirst, is here recommended; and many of the medicinal uses of the muriatic acid are dwelt upon at length, which have been claimed as recent discoveries. On the whole, there is no author contemporary with GLAUBER, who has written so much to the purpose, and in whom we find such abundant anticipations of modern scientific improvements. He was cast in the true mould of an experimental chemist, and had he lived in a more propitious age, would doubtless have rivalled the eminence of SCHEELE and of PRIESTLEY.

§ IV.

It is now time to advert to the early proceedings of the Royal Society, as connected with my present subject, a body incorporated by CHARLES II. in 1662, under a Royal Charter, for the improvement of natural knowledge. The period of the foundation of this Society was peculiarly favourable to its interests and objects; the country, long distracted by the worst of all evils, a civil war, and afterwards oppressed by the military usurpation of Cromwell, was threatened, upon the death of the Protector, with the horrors of anarchy, when the restoration of CHARLES II. healed all divisions, and checked the tide of revolutionary violence. Then was a propitious time to lead the rich and well-informed into the avenues of scientific inquiry, and to substitute the advancement of knowledge for political speculation. Among the first members of the Royal Society are the names of many who were eminent in mathematical and physical knowledge, and of more who afterwards became so; they were vehement in favour of experimental science, which was then in its infancy, and soon acquired vigour by their support; and it is curious to observe among the most active and zealous promoters of these peaceful studies, many who had been famed as party leaders, or actively engaged in political intrigues and revolutionary broils.

The early volumes of the *Philosophical Transactions*, of which the first bears date 1665, consist of small numbers, which were published at irregular intervals, and from their miscellaneous contents, may be compared to the scientific journals of these days. Exclusive of papers read before the Royal Society, they contain many scraps of literary and scientific value collected by the secretary, Mr. OLDENBURGH. The publication was continued by Drs. GREW and HOOKE, but the latter discontinued it, probably from the sparing sale; and in 1683 we find Dr. PLOT resuming the editorship, upon condition that the members would bind themselves to purchase sixty copies of each number. The *Transactions* were periodically published, with some intermissions, however, by the Secretaries of the Society, till the year 1750, when the publication was put into the hands of a Committee of Papers; and since the year 1762 a volume has annually made its appearance*.

In 1666, the Royal Academy of Sciences was instituted at Paris, under the protection of LOUIS XIV.; in its annals the names of HOMBERG, GEOFFROY, and the two LEMERYS, soon became celebrated for their various discoveries and improvements in chemistry. HOMBERG †, under the auspices of the Regent Duke of ORLEANS, was an active and successful experimentalist. He discovered the boracic acid, which he prepared under the name of sedative salt. He was also the discoverer of *Pyrophorus*. GEOFFROY deserves mention as an active and scientific contributor to pharmaceutical chemistry; he was also, I believe, the first compiler of the *Paris Pharmacopœia*.

The early proceedings of the Royal Society of London present many traits of the infant state of experimental science,

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* THOMSON'S *History of the Royal Society*.

† Born at Batavia, in Java, 1652; died at Paris, 1715.

and not a few absurdities might be selected from among them, the principal of which were lampooned by Sir JOHN HILL, in his *Review of the Works of the Royal Society of London*. This period, however, was adorned with the names of BOYLE* and of HOOKE†; the former a voluminous writer, of a most amiable temper and upright mind; the latter, an original and acute experimentalist, but a peevish and distrustful man‡.

Although Mr. BOYLE cannot be said to have fathomed the depths of science, yet his station in life, his mild and prepossessing disposition, his strict honour and integrity, and the unaffected earnestness with which he promoted experimental inquiry, tended to shed a lustre on his pursuits, to elevate their character with the world, and to draw into their precincts many who, without such an example, would have passed their lives in that listless inactivity, then too common with those upon whom fortune smiled; among them Mr. BOYLE made many converts. "It must be confessed," says his contemporary EVELYN, "that he had a marvellous sagacity in finding out many usefull and noble experiments. Never did stubborn matter come under his inquisition, but he extorted a confession

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* Boyle was born in January 1627, at Lismore, in the Province of Munster, in Ireland. He was educated at Eton, and afterwards travelled in Italy, Switzerland, and France, and returned to England in 1644. In 1668 he took up his residence in London; and in 1680 was elected President of the Royal Society. He died on the 30th of December 1691, aged 64.

† Born in the Isle of Wight, 1635: died in London, 1702.

‡ Sir Godfrey Copley, in a letter written about the time of Hooke's death, says, "Dr. Hooke is very crazy; much concerned for fear he should outlive his estate. He hath starved one old woman already, and I believe, he will endanger himself to save sixpence for any thing he wants." In another, written a few weeks after his death, Sir Godfreys says, "I wonder old Dr. Hooke did not choose rather to leave his £12,000 to continue what he had promoted and studied all the days of his life,—I mean mathematical experiments, than to have it go to those whom he never saw nor cared for. It is rare that virtuosos die rich, and it is pity they should, if they were like him." (*Dr. Ducarrel's MSS.* quoted in *Biog. Dict.*) Hooke sometimes declared, that he intended to dispose of his estate for the advancement of natural knowledge, and to promote the ends for which the Royal Society was instituted; to build a handsome edifice for the Society's use, with a library, laboratory, and repository, and to endow a professorship. (*Life by Waller.*)

of all that lay in her most intricate recesses, and what he discovered he has faithfully registered and frankly communicated. In this," says EVELYN, "exceeding my Lord VERULAM, who (tho' never to be mentioned without honour and admiration) was used to tell all that came to hand. His severer studies did not in the least soure his conversation, and I question whether any man has produced more experiments without dogmatising. He was a corpuscularian without Epicurus; a great and happy analyser addicted to no particular sect, but, as became a generous and free philosopher, preferring truth above all; in a word, a person of that singular candour and worth, that to draw a just character of him, one must run through all the virtues, as well as through all the sciences *."

Mr. BOYLE died in December, 1691, and his funeral sermon was preached by the celebrated Dr. BURNET, at St. Martin's Church, "in which," says EVELYN, "he spake of his wonderful civility to strangers, the greate good which he did by his experience in medicine and chemistry, the works, both pious and useful, which he published, the exact life he led, and the happy end he made †."

Upon the whole, it may truly be said of Mr. BOYLE, that, though he enlightened and adorned the avenues of science, he scarcely enriched it; he wrote much, and generally to the purpose, but he is rather the historian than the actor. It may be remarked, however, that in BOYLE, and especially in his contemporary HOOKE, we have the first genuine samples of the influence of Lord BACON's doctrines, which actuated all their proceedings, and produced effects marvellously beneficial. Mr. BOYLE's Essays on the successfulness and unsuccessfulness of experiments, and the preface to his philosophical writings, are in the genuine spirit of experimental research; and HOOKE, in the preface to the *Micrographia*, has spoken so much to the point, and in language so novel and bold in the then state of science,

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* BRAY's *Memoirs of Evelyn*, 2*d* edit. 4to., Vol. II., p. 268.

† *Ibid. Diary*. Vol. II. p. 30.

that, upon perusing it, we are struck with the entire confidence which it bespeaks for his subsequent experimental details.

After adverting to the deep-rooted errors that have been grafted upon science, by the slipperiness of the memory, the rashness of the understanding, and the narrowness of the senses; and shewing that these failings may in some degree be obviated by the right ordering and rendering them duly subservient to each other, he proceeds to point out the means of tracing the footsteps of nature, " not," as he says, " in her ordinary course only, but also in her doublings and turnings; and in this investigation, upon which the desirable reform in philosophy is to be founded, there is not so much required any strength of imagination, or exactness of method, or depth of contemplation, as a sincere hand and faithful eye, to examine and to record the things themselves as they really appear."

Hooke then goes on to lament that " the science of nature has been too long made the work of the brain and of the fancy; let it now revert," says he, " to plain and sound observation; and let all intelligence be severely examined; let there be rigour in admitting, strictness in comparing, slowness in debating, and shyness in determining. The understanding is to order all the inferior services of the lower faculties; but yet it is to do this as a lawful master, and not as a tyrant. It must not encroach upon their offices, nor take upon itself the employments which belong to either of them. It must watch the irregularity of the senses, but not go before them, or prevent their information; it must examine, range, and dispose of the bank which is laid up in the memory; but it must be sure to make distinction between the sober and well-collected heap, and the extravagant ideas and mistaken images which there it may sometimes light upon." This is, indeed, the language of Lord Bacon, by one who acted as he wrote, for Hooke was a most diligent experimenter, and has recorded his results with all that cautious sobriety which he advises. " If ever," he says, " I have ventured at small conjectures respecting the causes of the things I have observed, I beseech the reader to look upon them only as doubtful problems and uncertain guesses, not as unquestionable conclusions, or matters of unconfutable science."

Among the new views and discoveries of HOOKE, connected with chemistry, and many of which are scattered through the writings of BOYLE, there are none of more importance than those relating to the phenomena of combustion, and to the part which the air performs in that process; and as we are now approaching an epoch of our history at which the appearances presented by burning bodies, and the changes which they undergo, were attentively examined and assiduously inquired into, and in which they were considered as one of the main objects of chemical research, it is right that we distinctly understand HOOKE's notions upon this subject, which will be found wonderfully acute, and remarkable for their boldness, as differing from theories then received; and for correctness as superseding the objections that the other views are liable to.

From the obscure hints that are to be found in the writings of the alchymists, and from the more decided language of BASIL VALENTINE, PARACELSUS, and other writers of that cast, it appears that the phenomena of combustion were generally referred to the existence of some subtile and highly volatile principle, which, expanded and agitated by heat, produced flame and fire. When metals were exposed to the action of heat, the greater number were observed to alter their appearance, and, losing metallic brilliancy, became converted into an earth-like residue, to which the name of *Calx* was given. It was generally admitted that, in this process, the particles of the combustible were thrown into violent vibrations, and so transformed into heat and light; and such a supposition was natural enough, for it appears to a superficial observer, unacquainted with the powers of modern discovery, that the matter burned is, in the greater number of cases, entirely consumed, and that the principal products are light and heat.

A tract extremely remarkable for the period at which it was written, appeared on this subject in France about, or previous to, the year 1630, relating to the increase of weight sustained by tin and lead during their calcination. Le Brun having melted two pounds six ounces of tin, found that in six hours the whole had passed into the state of calx, weighing three pounds one ounce; and being puzzled at the circumstance, he consulted Rey, a physician of Perigord, as to its cause, who immediately set about an investigation of the matter, which terminated in explicitly referring the cause of the increase to the fixation of air*.

Hooke in his investigations, and Boyle by his experiments with the air-pump, which was now just perfected and coming into use, succeeded not merely in demonstrating the important part performed by the presence of atmospheric air in combustion, but Hooke carried his inquiries still farther; and, in his mind's eye at least, seems to have seen and anticipated the results that were gained at a much later period of chemical science, and established upon a less questionable authority.

Boyle found that a candle, charcoal, sulphur, and some other combustibles, would not burn in the exhausted receiver of his air-pump, which however produced a very imperfect vacuum. When he had procured a good vacuum, he found that gunpowder would not inflame in it by collision of flint and steel, which he very properly attributed to the want of due heat in the sparks resulting from collision: for, on heating the powder violently by a burning lens, it exploded: hence he thought the nitre contained in the gunpowderw as concerned in furnishing materials to supply the place of the air†.

Hooke, in the sixteenth section of the *Micrographia*, relating

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* *Essays de* Jean Rey, *Docteur en Médécine, sur la Recherche de la Cause pour laquelle l'Estain et le Plomb, augmentent de poids quand on les calcine.* Paris, 1717.

† New experiments touching the relation betwixt flame and air. Boyle's *Works*. 4to. London, 1772. p. 563.

to charcoal and burned vegetables, observes, that in the ordinary process for making charcoal, the consumption of the wood is prevented by the exclusion of atmospheric air. The charcoal glows, it is true, but does not burn;—hence, he says, may we learn, that the air is the universal dissolvent of inflammable bodies,—that this dissolution generates heat, which we call fire, as is the case in many other dissolutions,—that this dissolution is made by a substance mixed with the air that is like unto, or the *very same*, as that which is fixed in saltpetre,—that of the burning body one portion is turned into air, and another portion is indissoluble,—that the dissolving parts of the air are but few, and hence the atmosphere is like those spirits that have much phlegm mixed with them, and become soon glutted; whereas saltpetre abounds more in those solvent particles, and hence a little will dissolve a great sulphureous body quickly and violently; and as other solvents, though but weak, quickly consume the dissoluble body, if the supply be renovated, so air, applied to a shining body by a bellows, will dissolve it as rapidly as saltpetre. From all which he concludes, that there is no such thing as an element of fire, but that flame results from the mutual agency of the volatile parts of combustibles, and a part of the atmosphere.

These although not the very words of HOOKE, but an abridgment of them, contain their unadulterated sense, and present a permanent and remarkable monument of his sagacity and penetration: his expressions shew that he had experimented more largely upon the subject, but he was unwilling to extend his account of it till he had completely investigated other parts of the inquiry; he particularly alludes to the use of the air in respiration. I do not, however, find in any of HOOKE's later productions that he followed up the very interesting facts detailed in the *Micrographia*, though in his *Lampas*, published in 1677, he has given a very beautiful explanation of the way in which a candle burns: he attributes the light and heat to the action of the air upon the combustible matter of the flame, and shews that the interior of the flame is not luminous, by the simple expedient of viewing its section through a thin piece of glass, or of mica.

The doctrines of Hooke, concerning the influence of the air in combustion, were further illustrated by John Mayow[*], who, in 1674, published his *Tracts on various Philosophical Subjects.* The date of this work is posterior to that of the *Micrographia,* but anterior to the *Lampas,* and it contains arguments very similar to those promulgated in the former work, without, as far as I have been able to find, any reference to them, or even mention of Hooke's name. But Mayow's chemical fame need not be built upon his doctrine of combustion, for he has displayed uncommon talents in various other branches of inquiry.

While these views were promulgating in England, and chemists were busy in endeavouring to raise a theory of combustion, independent of hypotheses, and founded upon experimental inferences only, Beccher[†] and Stahl[‡], in Germany, were at work upon the same subject, and succeeded in establishing an explanation of combustion, which afterwards made much noise abroad, under the name of the Phlogistic Hypothesis; and when we revert to the researches whence this hypothesis arose, they carry with them so plausible and accurate an air, and appear so much less at variance with received doctrines, and known facts, that it is not surprising they should have been adopted in preference to the more abstruse and, as they then appeared, hypothetical explanations of Hooke and Mayow.

Beccher's *Physica Subterranea*[§] was published at Franck-

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[*] Born in Cornwall, 1465; died in London, 1697.

[†] Born at Spires in 1625; died in England, 1685.

[‡] Born in Franconia, 1660; died at Berlin, 1734.

[§] Beccher wrote voluminously upon a great variety of subjects. His principal chemical works are as follows:

1. *Oedipus Chemicus.* 2. *Metallurgia, de generatione, refinatione, et perfectione Metallorum.* 3. *Physica Subterranea,* and its various appendices. 4. *Par-*

fort in 1669: I have endeavoured in vain to come at the meaning of much of this publication; but thus far I have learned, that he has anticipated the prevailing geological theories of the present day, and has argued upon many terrestrial phenomena, with a degree of plausibility and precision which will bear comparison with the more enlightened and learned views of HUTTON and PLAYFAIR.

His notion of the chemical constitution of bodies amounts to this: the elements of bodies are air, water, and three earths, one of which is inflammable, another mecurial, and another fusible. The three earths, combined with water, constitute an universal acid, which is the basis of all other acids. The combination of two earths produces lapideous bodies; and, in the metals, the three earths are united in various proportions. I cannot pretend to explain or elucidate this doctrine, and have no further remark to make upon it, than to request it may be compared with the luminous *experiments* of HOOKE, in order to set the merits of the latter in their true light.

Towards the end of the seventeenth century, the opinions promulgated by STAHL attained universal assent, and of the names of HOOKE and MAYOW nothing was heard for more than half a century.

Rejecting the mercurial earth of BECCHER, STAHL retained

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nassus Medicinalis Illustratus. 5. *Laboratorium Portatile.* 6. *Chymischer Rosen-garten.*

Beccher's *Oedipus* is dedicated to Francis Sylvius Deleböe, who, in 1658, was elected the first Professor of Medicine in the University of Leyden. He was a man of an acute mind, as appears from his various essays and tracts, more especially from his *Praxeos Med. Idea Nova.* He died at Leyden in 1672. "Utilissimum profecto munus subiisti, quo tui auditores non verba sed corpora, non chymerasticos terminos, verum ipsas reales enchyrises, non inanes denique et immateriales facultates, sed a te demonstrati, effectus causas practicas audiunt, vident, tangunt." Beccher everywhere compliments him as a man not of words, but of deeds; as a philosopher, who eminently sought to render science popular and intelligible to all capacities.

The language of Beccher's *Physica Subterranea* is sufficiently inelegant and incorrect. "Excuso *Latinitatem* in hoc opere," says he, "quam *barbaram* esse fateor, ob materiem et ob scriptionem, in specie scriptionis modum: ex ore enim dictantis totum opus conceptum est. Sic *rebus* attentus, *verba* neglexi." This is at once an example and apology.

as elements, water, acid, earth, and fire, or, as he termed it, *Phlogiston*, a principle of extreme tenuity, and prone to a kind of vibratory motion in which it appears as *fire*. He went beyond BECCHER in adducing experimental proofs of his hypothesis. When phosphorus is burned, it produces an acid matter with the evolution of much heat and light; consequently, phosphorus consists of acid and phlogiston: if this acid be now heated with *charcoal*, or other body abounding in phlogiston, phosphorus will be re-produced.

When zinc is heated to redness, it burns with a brilliant flame, and is converted into a white earthy substance or calx. Hence zinc consists of this earth and phlogiston.

Now, it will be observed, that nothing is said here of the increase of weight which REY attributed to the condensation of air, and which MAYOW has as distinctly referred to the fixation of HOOKE's nitro-aërial particles. Nor is that obstacle taken into the account which BOYLE's experiments had suggested, and which HOOKE is particularly fond of dwelling upon, namely, that bodies will not burn without air.

However, this hypothesis of STAHL, notwithstanding the increase of weight in the burning body, the requisite presence of air, and other bars against it, was immediately embraced by the generality of chemists, and maintained an unimpeached dominion for upwards of fifty years, until shaken and upset by the arguments of LAVOISIER, who, availing himself of the discoveries of SCHEELE, PRIESTLEY, and BLACK, brought an insuperable mass of evidence to bear against the doctrine of phlogiston*.

That constituent of the air which HOOKE had detected in

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* Stahl's doctrines are very ably set forth in his Three Hundred Experiments, published at Berlin in 1731; and in his Fundamenta Chemiæ, Nuremberg, 1723 and 1732. He noticed the necessity of air to combustion, but he considered flame or fire as resulting from its violent etherial agitations. Stahl is continually urging circumspection in hypotheses, yet preconceived opinions are always leading him to erroneous conclusions, as the following passages amply prove. "Aer ignis est anima, hinc, sine aere nihil potest accendi vel inflammari."—"Aer in motum excitatus, seu ventus artificialis, vel etiam naturalis, mirum excitat motum ætheris

nitre, and which Mayow called its nitro-aërial particles, was, under the new title of *oxygen*, regarded as accessory to all cases of combustion. It was presumed that this aërial matter consisted of heat and light, combined with a ponderable base which united with the combustible, conferring upon it new characters, while the other elements were extricated under the form of fire. But to this explanation two difficulties soon presented themselves; the one, that in many cases of combustion, aëriform matter, instead of being absorbed and decomposed, is evolved and composed; and the other, that the evolution of heat and light is not proportional to the volume of air condensed, but depends upon the rapidity of the condensation, and upon the nature of the combustible.

These objections cannot be fully discussed, without a reference to the doctrines of heat, which now must not be entered upon. It has been endeavoured to explain them away, but these explanations are fraught with new difficulties. The aid of electricity has been called in, but only with partial success; and we must be content to consider combustion as a result of intense chemical action, the ultimate cause of which is still undisclosed.

We may, however, glean some profit upon the field of discussion that we have passed over. It may teach us circumspection in adopting hypotheses, and caution in deductions even from experiments; while, in the views which have successively risen and vanished, in the confident security with which they have at one time been received, and the unceremonious neglect into which they have subsequently fallen, we have painted as it were before us, a striking memento of the frailty and insignificance of human exertions.

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seu flammam; hinc ad ignem fusorium, et vitrificatorium, promovendum, follibus opus est; imo gradus et vehementia ignis dependet multum ex aeris admissione." —*Fund. Chem. dogmat. et ration.*, p. 22.

§ V.

Mayow, whose name was mentioned in the last section coupled with that of Hooke, in researches concerning the influence of air upon combustion, is the first writer who divulged views worth recording upon the subject of respiration, and who has elsewhere displayed some shrewd guesses concerning the causes and effects of chemical affinity. In the first case, he opened a communication between chemistry and physiology; and, in the latter, he extricated a most important and fundamental branch of chemical philosophy from the mire of false reasoning, and planted it in the meadows of experimental research.

Mayow was the ornament of his time and country as an experimental inquirer; but, unfortunately, he seems to have fallen upon unpropitious ground, and his talents, instead of having been awakened by emulation, were damped by the coldest reception. He was a native of Cornwall, and died at the early age of thirty-five, at the house of an apothecary in York-street, Covent Garden. Dr. Beddoes, and more lately Dr. Yeats *, have each asserted his claims to several of the discoveries attributed to modern experimenters, and they have in many points made out an irresistible case in his favour.

At an early period of his experiments, Mayow seems to have been struck with the analogy between the phænomena of combustion, and those of respiration, and although many of his conclusions are full of error, there are more which are correct and even refined. He burned a candle under a bell-glass, and found the air so deteriorated as to be unfit for the continuance of combustion. He then confined a mouse in a similar portion of air, and it soon manifested the want of its

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* Observations on the Claims of the Moderns to some Discoveries in Chemistry, &c. By J. D. Yeats, M.D. London, 1798.

renewal. Then, by putting a mouse and a candle under the same bell-glass, he found it live only half the time that it had survived when under the glass alone. He then reversed the experiment, and endeavoured to fire combustible matter in air that had been spoiled by breathing; and finding that it would not burn, he observes, that "the nitro-aërial particles are absorbed both by the candle and the animal *."

Examining the residuary air standing over water after combustion, he found that it was a little lighter than the atmosphere, and extinguished flame; thus remarkably describing nitrogen by its principal properties, namely, that it does not support combustion, that it is not absorbed by water, and that it is lighter than atmospheric air.

When Mayow speaks of the *destruction of the elasticity* of a portion of air, he alludes to its absorption by water; and finding the carbonic acid, formed by respiration and combustion, to be thus absorbed, and its formation always connected with the loss of power to support flame, or of its nitro-aërial parts, he talks of restoration of elasticity by restoring the nitro-aërial matter.

Besides the nitro-aërial part, or oxygen, the absorbable part or carbonic acid, and the remaining nitrogen, Mayow obtained hydrogen gas by acting upon iron by dilute vitriolic acid; and nitrous gas, by immersing the same metal in dilute *aqua-fortis*. Upon the whole, Mayow's experiments upon respiration, and upon the gases, are something more than ingenious. Considering the novelty of the subject, and the imperfection of his apparatus, they may be considered as surprising efforts of experimental diligence, and his conclusions may be ranked as remarkable indications of a fruitful mind, not wandering amongst hypotheses, but settling upon the results of experiment. Not satisfied with having ascertained that one part only of the atmosphere supports life, he extended

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* See the 1st and 2d Tracts, *de Sal-nitro, et Spirito Nitro-aërio,* and *de Respiratione.*

his inquiry to the subsequent influence of that part upon the system. It was the prevailing notion of his time that respiration cooled the blood, but having observed in the nitro-aërial or fire-air particles an essential to flame and fire, he considered their absorption as necessarily connected with the heat of the blood; he observed an analogy between the respiration of animals and that of plants; and to show the existence of air in the blood, he had recourse to the air-pump, which, he says, extricates it more copiously from arterial than from venous blood.

The most remarkable Chapter, however, of MAYOW's tract, is that relating to the "mutual action of salts of contrary kinds," or, in other words, to chemical combination and decomposition, a subject which he has handled in so masterly a manner, and which is so ably supported by experiments, that although anticipated in respect to his researches on the air by HOOKE, we must here give him due credit as an original inquirer..

It was imagined by those predecessors of MAYOW who expounded their notions respecting chemical affinity, that bodies combined in consequence of certain mechanical forms of their particles; and that when an acid was added to an alkali, the salt produced was a perfectly new product, resulting from the annihilation of the particles of its components. It was not admitted, or at least not generally admitted, that the acid and alkali existed as such, and might again be separated from the neutral salt. MAYOW first set about rectifying this gross error. When spirit of salt, he says, is mixed with *sal volatile*, (or, to use more intelligible terms, when muriatic acid is saturated with ammonia) sal ammoniac is produced, in which, it is true, neither the properties of acid, nor of alkali, are apparent; yet, if salt of tartar be distilled with sal ammoniac, the volatile alkali will be displaced with all its previous characters, because there is a greater attraction between spirit of salt and tartar than between spirit of salt and volatile alkali. Again, to show that the acid is not destroyed in saline combinations, he instances the decomposition of nitre by oil of vitriol, which, he says, displaces the nitric acid, and the residuum in the retort furnishes vitriolated tartar. It may be asked, he says, why, when nitre is heated, the nitric acid does not rise, for it is, as we have just seen, very volatile: the reason is, that it is restrained and kept down by its attraction for the tartar, and can only be displaced by bodies which have a stronger attraction for tartar than it.

This is very excellent reasoning, and it would be difficult, with all the advantages of modern acquisitions, to adduce two more illustrative cases than those which MAYOW has furnished.

He then goes on to show, that acids have a greater attraction for alkalies than for metals. The metals, he says, are soluble in one or other of the acids, but their solutions are decomposed by salt of tartar; the acid then combines with the tartar, and the metal is precipitated. In the same way alkali unites to sulphur; but if this combination be dissolved in water, and acid added to the solution, the sulphur falls, and the acid and alkali unite.

Combinations of the metals with sulphur are also decomposed by acids: thus if sulphuret of antimony be distilled with aqua-fortis, the acid and metal combine, and sulphur sublimes.

Having given other similar instances of the combination of sulphur with metals and alkalies, he proceeds to some general views connected with the subject, among which the following deserve particular notice.

Although, he says, sulphur enters into these combinations, we are not to imagine, as some have done, that sulphur includes an acid, and thence derives its powers of combination, in consequence of its containing an opposite nature: on the other hand, it is clear, he adds, that the combination is independent of any such hidden cause, and is the mere result of the mutual affinity of the substances. He then cautions those concerned in the compounding of medicines, to beware of the new compounds that may result in consequence of these mutual attractions and decompositions, for "one substance may destroy the efficacy of another, and something perfectly different from the original may result."

It is curious, he remarks, that when acid of vitriol is poured upon salt of tartar, so as to form vitriolated tartar, a great effervescence ensues; but if the acid be previously combined with a metal, this is not observed, and yet vitriolated tartar is equally formed; as when salt of tartar is added to solution of green vitriol. In these cases, he says, the acid part of the salt of tartar is retained by the metal; thus giving a curious and explicit account of a frequently occurring case of double decomposition.

These views, relating to chemical attraction, are at once clever and correct, and their merit will be especially enhanced by a comparison with the absurd and groundless speculations previously entertained upon this subject, which, indeed, are too crude and silly to merit repetition. But MAYOW has other and more weighty evidence in his favour, for it is remarkable that his views and language were adopted by NEWTON, and that the masterly sketch of a theory of chemical attraction given by that philosopher in the Queries annexed to the third book of Optics, is nearly in the language, and quite in the spirit and meaning, of his predecessor MAYOW. The following are a few of the points urged by NEWTON in the explication of these phænomena:—

If carbonate of potash be exposed to air it deliquesces, in consequence, says NEWTON, of an attraction between the salt and the particles of water contained in the atmosphere. And why does not common salt and saltpetre deliquesce in the same way, except for want of such attraction?

And again, where he especially comes in contact with MAYOW, he says, when spirit of vitriol, poured upon common salt or saltpetre, makes an ebullition, and affords on distillation the muriatic and nitric acids, the acid part of the spirit of vitriol staying behind, does not this argue that the fixed alkali in the common salt and saltpetre attracts the acid spirit of the vitriol more strongly than its own spirit, and not being able to hold them both, lets go its own? How these attractions may be performed, continues NEWTON, I do not here consider; what I call *attraction* may be performed by impulse, or by some other means unknown to me: I use that word to signify any force by which bodies tend towards one another, whatever be the cause. Thus, he says, muriatic acid unites to salt of tartar, by virtue of their respective attractions; but when oil of vitriol is poured upon this compound, the former acid is displaced by the superior attraction of the latter. Silver is separated from aqua-fortis by quicksilver; quicksilver by copper; and copper by iron; which argues that the acid particles of the aqua-fortis are attracted more strongly by iron than by copper; by copper than by quicksilver; and by quicksilver than by silver*. Thus, then, chiefly by the experimental labours of MAYOW, and the sagacious views of NEWTON, the old and prevailing notions of the atomic forms of bodies, the hypothesis of hooks, rings, points, and wedges, by which the component parts of bodies were supposed to be held united, gave way to the simple and independent expression of facts.

It has often been said, that the anticipations of modern discoveries which could alone be demonstrated by the progress of experimental research, are very characteristic of the writings of NEWTON, and the proof of his superior sagacity and penetration: he said that the diamond consisted of inflammable matter, and suspected the existence of a combustible element in water, very long before either of those subjects had been experimentally investigated; and in his notions relating to the

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* Newton's Optics. Book III. Query 31.

subject of chemical attraction, he has an anticipation not less striking, relating to the connexion between chemical and electrical attraction. "The attraction of gravity, magnetism, and electricity reach to very sensible distances, and so have been observed by vulgar eyes; and there may be others which reach to so small distances as hitherto to escape observation, and perhaps electrical attraction may reach to such small distances without being excited by friction*."

I shall conclude this subject with some account of the progress that has been more lately made in elucidating the doctrines of chemical attraction.

In 1718, GEOFFROY† invented those tables of affinity which are now given in elementary works, and which have certainly proved of service in extending chemical knowledge; he considered the order in which bodies separate each other from a given body, as permanent and constant. Thus, he thought the metals were always separated from acids by the absorbent earths, these by volatile alkali, and the volatile by the fixed alkalies; to represent, therefore, the attraction of acids for these substances, he placed them at the head of a column, with the other bodies beneath, in the order of attraction.

ACIDS.

Fixed akalies.
Volatile alkali.
Absorbent earths.
Metals.

He then constructed a column for each particular acid; thus the table for nitric acid taken from NEWTON's experiments would stand as follows:—

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* Optics, Book III.

† Mem. Paris, 1718.

Nitric Acid.

Fixed alkali.
Volatile alkali.
Earths.
Iron.
Copper.
Lead.
Mercury.
Silver.

Gellert and Limbourg in 1751 and 1758, extended and, in some respects, improved these tabular representations of the results of attraction; but no considerable progress was made in the investigations connected with the subject, until Bergman* published his dissertation upon it in 1775.

Of Bergman's character and merits as a chemist, I shall speak more at length hereafter, confining myself at present to the views which he entertained upon the subject of affinity, or, as he called it, *elective attraction*†.

Bergman considered that every substance possessed a peculiar attractive force for every other substance with which it combines; a force capable of being represented numerically: he regarded decomposition as complete; that is, whenever a third body *c* is added to a compound *a*, *b*, for one of the constituents of which it has a stronger attraction than that which already exists between them, the compound will be decomposed, and the whole of one of its elements transferred to the added body. Thus, supppose the attraction of *a* for *b* to be represented by 1, and of *a* for *c* by 2, then the addition of *c* to *a b* will produce the compound *a c*, and *b* will be separated. When lime-water is added to nitrate of magnesia, the latter earth is precipitated, and the former combines with the nitric acid. Hence, nitric acid poured upon a mixture of lime and magnesia, dissolves the former, in preference to the latter earth.

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* Torbern Bergman, born in Sweden, 1735; died 1784.

† De Attractionibus Electivis. Opuscula, Vol. III. p. 291.

The observation of these facts led Bergman to call this kind of attraction *elective*, and he has given tables, shewing these relative attractions of bodies in the dry and humid way. Thus,

Silver.	Oxide of Silver.
Lead.	Sulphuric acid.
Copper.	Oxalic.
Mercury.	Phosphoric.
Bismuth.	Nitric.
Tin.	Tartaric.
Gold.	Critic.

Bergman's opinions relating to affinity were generally admitted as correct, and considered as standard authority, till Berthollet published his work on *Chemical Statics* in 1803, in which he endeavoured to revive, under a new aspect, some of the old chemico-mechanical doctrines, and to prove that the forms of the acting particles, and their magnitude, or masses of matter, were concerned in influencing the results. Though these doctrines may now be considered as exploded, they had many advocates, and were rapidly gaining ground until the promulgation of the theory of definite proportionals. The experiments adduced by Berthollet in support of his hypothesis, appeared at first very satisfactory; but upon minute inspection they have their weak points, and many of the errors into which they led have been successfully unravelled by Professor Pfaff, of Kiel; by Sir H. Davy, and others. In illustration of the agency of the mass of matter, Berthollet has adduced the mutual action of sulphate of potassa and baryta: when solution of baryta is added to sulphate of potassa, potassa is liberated, and sulphate of baryta is formed and precipitated insoluble; but if a large quantity of potassa be added to a small quantity of sulphate of baryta, the mass will, according to Berthollet, prevail over what appears to be the real chemical affinity, and sulphate of potassa will be formed, and baryta evolved. But Sir H. Davy has very ingeniously exposed the fallacy to which this experiment is liable: he has shown that pure potassa does not effect any change upon sulphate of baryta, but that making the experiment in open vessels, part of the potassa acquires carbonic acid, and then a double affinity is brought into action, the bodies present being carbonate of potassa and sulphate of baryta*.

Berthollet's notion, that the acting bodies are divided among each other in proportions depending upon their relative masses and attractions, has been combated and disproved by Pfaff †, who has shown that tartrate of lime is completely decomposed, by adding to it a quantity of sulphuric acid exactly sufficient to saturate the lime it contains; and in the same way he has shown that oxalate of lead is decomposed, by adding sulphuric acid sufficient to saturate the oxide of lead: in these cases pure tartaric and oxalic acids are evolved.

But the establishment of the Atomic Theory, from which we learn that bodies combine only in certain definite proportions, has gone further to elucidate the very important subject of chemical attraction, and to subvert the doctrines of Berthollet, than any previous objections or partial experimental investigations. In establishing this theory all the eminent chemists of Europe have taken an active part, so that it becomes very difficult to assign to each his individual merit.

Between the years 1792 and 1802, Dr. Richter ‡, of Berlin, published his *Geometry of the Chemical Elements*, containing a series of tables, showing the weight of each base, capable of saturating one hundred parts of each acid; and the weight of each acid capable of saturating one hundred of each base. He observed that in all these tables the bases and the acids followed the same order: and further, that the numbers in each table constitute a series having the same ratio to

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* Elements of Chem. Philos., p. 119.

† Annales de Chimie. LXXVII.

‡ Anfangsgründe der Stochiometrie oder Messkunst Chemischer Elemente.

each other in all the tables. Thus, supposing in the table of sulphates, one hundred parts of acid were saturated by one hundred of soda, two hundred of potassa, and three hundred of baryta; then in the table of nitrates the same ratio would hold good, and the soda, potassa, and baryta would there also stand to each other in the relation of one, two, and three.

Thus was explained why, when two neutral salts decompose each other, the newly formed salts are also neutral; for the same *proportion* of bases that saturate a given weight of one acid, saturate a given weight also of all the other acids. Hence numbers may be attached to each acid and to each base, indicating the weight of it, which will saturate the numbers attached to all the other acids and bases. Upon this principle, elementary works on chemistry contain tables of the representative numbers of bodies; and upon the same principle, Dr. WOLLASTON *, by adapting such table of numbers to a moveable scale, on the principle of GUNTER's sliding rule, has constructed the *logometric scale of chemical equivalents*, which is so important and valuable an instrument to the practical chemist.

Mr. HIGGINS, in 1789 †, and Mr. DALTON, in 1804 ‡, called the attention of chemists to the definite proportions in which bodies unite that form several compounds. Thus, seventy parts of potash unite to thirty of carbonic acid, and to sixty, but not to any intermediate proportions. If we represent the weight of nitrogen by 14, it will form the following compounds with oxygen:—

Nitrous oxide . .	14 + 8 oxygen.
Nitric oxide . .	14 + 16
Hyponitrous acid .	14 + 24
Nitrous acid . .	14 + 32
Nitric Acid . .	14 + 40

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* Philos. Trans. 1814.

† Comparative View of the Phlogistic and Anti-phlogistic Theories.

‡ New System of Chemical Philosophy.

Similar observations apply to all other bodies: and it was hence that Mr. DALTON was induced to assert, that these proportional numbers represented the respective weights of the atoms of combining bodies; and one atom of nitrogen was said, in the above case, to combine with one, two, three, four, and five atoms of oxygen.

In selecting the body which should be assumed as unity in this numeric representation, Mr. DALTON adopted hydrogen; and I am induced, for several reasons, to follow his example, though there has been weighty authority in favour of oxygen.

In applying the theory of definite proportionals to aëriform bodies, GAY LUSSAC * has considered them as determinable by volumes, a view which clashes with parts of Mr. DALTON's atomic hypothesis, but which may be adopted, independent of hypothetical views, as a beautiful expression of facts.

§ VI.

BEFORE we proceed with the regular thread of our historical narrative, which is now carrying us into that eventful period for chemistry, and indeed for the progress of all the sciences, the first half of the eighteenth century, it is requisite rapidly to review some collateral investigations which occupied the philosophers of the seventeenth century, and which, though not strictly chemical, contributed much to the progress and perfection of some of the more difficult and abstruse branches of that department of knowledge.

Of these inquiries it will especially be right to notice such as relate to the phænomena and effects of heat, which, in consequence chiefly of the invention of the thermometer, were pursued with a degree of ardour and success, highly creditable

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* Memoires d'Arcueil, ii. 207.

to the diligence and sagacity of the individuals concerned. Among them, Boyle is entitled to particular praise; and though his inquiries are blended with much irrelevant and miscellaneous digression, they contain materials amply important and interesting—materials which paved the way for some of the most eminent achievements in chemical science.

It has been disputed to whom the honour of inventing the thermometer belongs; some have given it to Cornelius Drebbel *, and some, with more plausibility, to Santorio † of Padua. But, when we reflect upon the imperfection and comparative uselessness of the instrument attributed to those claimants, and when the construction of the thermometer now in use may be indisputably referred to the Florentine Academicians, the disputes respecting priority become of little importance. Air was first used as a means of exhibiting, by its expansion and contraction, the alternations of heat and cold; and Van Helmont has described, with some minuteness, several modifications of the air thermometer ‡.

But however valuable such thermometers may be for particular purposes, they are rendered extremely inconvenient by the rapid and great dilatability of air by moderate changes of temperature: besides which, it is almost impossible to construct air thermometers so as to agree among themselves in indicating the same degree, when applied to bodies of similar temperature.

The Academicians del Cimento were the first to employ thermometers constructed as we now see them. They used tubes, with a bulb containing spirit of wine, and closed so as to exclude the influence of air, and prevent the evaporation of the liquid.

This thermometer, though much superior to, and more

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* Born in Holland, 1572; died in London, 1634. He is also said to have invented the microscope.

† Born at Capo d'Istria, 1561: died at Venice, 1636.

‡ Opera Omnia, Art. Aër, p. 61.

useful than the old air thermometer, was yet an useless instrument, if we speak of it comparatively with those now constructed; for, there being no fixed point at either extremity of the scale, the graduation was arbitrary, and no two instruments, when placed in an atmosphere of the same temperature, indicated the same degree of heat.

There is some confusion in this part of the history of the thermometer, for, though the Florentine Academicians state that their scale generally commenced at the temperature of freezing, they represent that point by various terms or degrees, unsusceptible of comparison, and say nothing of the differing temperature of ice, which may exist at 32°, or any inferior degree. In Italy, however, it is most probable that the ice was in a thawing state, and therefore about 32° of FAHRENHEIT's scale; but all registers of the weather, and all enumerations of high and low temperatures are quite unintelligible, as recorded by experimentalists of that period.

"The great and truly honourable Mr. BOYLE" turned his mind with much earnestness to the construction of a scale for thermometers, and seems to have had it in contemplation to set out with the temperature at which water *begins* to freeze; "but the objections which he apprehended might be made to this method scared him so much," says Dr. MARTINE[*], "that he prosecuted no farther this consideration of fixing a standard for making and graduating thermometers all in the same way." Dr. HALLEY[†] observed, that the same thermometer always indicated the same temperature in places deep under ground, where neither the heat of summer nor the cold of winter seemed to produce any effect; and MARRIOTTE and DE LA HIRE had made the same remark upon thermometers placed in the caves of the observatory at Paris.

But, according to MARTINE, whose authority, as far as I have been able to trace his references, is, in most respects,

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[*] Essays Medical and Philosophical. By G. Martine, M.D. London, 1740.

[†] Phil. Trans., Abr. ii. p 36.

very exact, gives Dr. Halley the merit of fixing upon the boiling point of water as a standard of graduation, which elevates the quicksilver in the thermometer tube always to a given point, under given barometrical pressure; and the mean pressure of 30 inches of mercury is generally understood to be that to which our thermometers are graduated. Sir I. Newton employed the freezing and boiling of water as fixed points, but he used linseed oil to fill his tubes, a liquid inconvenient from its viscidity, and from the irregularity of its expansion. Alcohol was first used by the Florentine Academicians, because it is very sensible to changes of temperature, and remains clear in the tube; but, since its boiling point is much below that of water, it is useless for the measurement of high temperatures, though, from not freezing, admirably suited to indicate extreme cold.

For general convenience and equability of expansion, mercury, first used, I believe, by Dr. Halley, takes precedence of all other liquids. It bears nearly a red heat before conversion into vapour, and sustains the most intense cold of these latitudes without freezing; hence it is the liquid generally used for accurate and delicate thermometers.

The principal thermometric scales in use in Europe are, Fahrenheit's, which commences at the temperature produced by mixing snow and salt, and which is 32° below the freezing of water, so that the latter point is marked 32°, and the boiling point 212°, the intermediate space being divided into 180°: Reaumur's, in which the zero is the freezing point, and 80° the boiling point; and the *Centigrade*, in which the space between the freezing and boiling of water is divided into 100°.

There are some other circumstances connected with the construction and indications of the thermometer, which I at present pass over, reserving them for notice till we consider the more refined investigations relating to the subject of heat, which were undertaken at a subsequent period: in the mean time we may advert to the discovery of a very singular property possessed by water, which, as far as concerns the influence of heat upon it, distinguishes it from all other liquids. This anomaly was first observed by the Florentine Academicians: "We know," they say, "that water, in passing into the state of ice, suffers great expansion, a fact sufficiently evident from the violence with which various vessels are broken and rent asunder during the freezing of water in them; but it was not known to us at what particular period of refrigeration this expansion occurs; nor could we learn it from our former experiments, which were made in vessels of silver, gold, brass, and other strong, but opaque materials. We, therefore, now employed glass flasks, and observed, that the moment they were immersed in ice, the water in the neck of the flask was suddenly elevated, that it then began gradually to fall, and at length remained for a few moments quite stationary; then it began again to rise with a slow, but apparently equable progress at first, but afterwards sprung up so suddenly, that the eye could scarcely follow it *."

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* The following unaffected narrative of this celebrated experiment is very different from the usual verbose and pompous style of the philosophers of the period.

"Già sapevamo per innanzi (e lo sa ognuno) che il freddo da principio opera in tutti i liquori ristrignimento, e diminuzione di mole, e di ciò non solamente n'avevamo la riprova ordinaria dell' aquarzente de' Termometri, ma n'avevamo fatta esperienza nell' acqua, nell' olio, nell' argentovivo, ed in molt' altri fluidi. Dall' altro canto sapevamo ancora, che nel passaggio, che fa l'acqua dall' esser semplicemente fredda al rimuoversi dalla sua fluidità, e ricever consistenza, e durezza coll' agghiacciamento noc solo ritorna alla mole, ch' ell' aveva prima di raffreddarsi, ma trapassa ad una maggiore, mentre se le veggon rompere vasi di vetro, e di metallo con tanta forza. Ma qual poi si fosse il periodo di queste varie alterazioni, che in essa opera il freddo, questo non sapevamo ancora, ne era possibile d'arrivarvi con agghiacciarla dentro a' vasi opachi, come quei d'argento, d'ottone, e d'oro'ne' quali s'era fin' allora agghiacciata: Onde per non mancare di quella notizia, che parea esser l'anima di tutte quest' esperienze, ricorremmo al cristallo, ed al vetro, sperando per la transparenza della materia d'aver presto add' assicurarci come la cosa andasse, mentre si poteva a ciascun movimento, che fosse apparso nell' acqua del collo, cavar subito la palla dal' ghiaccio, e riconoscer in essa quali alterationi gli correspondessero. Ma la verità si è, che noi stentammo assai più che non ci saremmo mai dati ad intendere, prima di poter rinvenire alcuna cosa di certo intorno a' periodi di questi accidenti. E per dirne più distintamente, il successo è da sapere, che nella prima immersione, che facevamo della palla, subito, In Birch's *History of the Royal Society*, under the date of the 6th of February, 1683, we find some experiments on the freezing of water made before that body, in consequence of a letter received from Mr. Musgrave, of Oxford. "Dr. Croune said, he had observed water put into a bolt-head rise higher before freezing. Mr. Hooke attributed this to the shrinking of the glass. Dr. C. said, the glass had been long in the cold before, and the water rose immediately. Dr. Wallis proposed that an empty glass might be well cooled in a freezing liquor, in order that it might have its contraction before the water be put into it. This was done immediately by Mr. Hunt, and the water being put into a small bolt-head rose in the neck."

Numerous and correct experiments have completely established this peculiarity in the freezing of water; all other fluids have their maximum of density just before the freezing point; water expands before it freezes, and consequently water at 36° is lighter than water at 40°, and floats upon its surface: hence it is, that large masses of water, being cooled by the atmosphere upon their surface, only freeze there, and the water beneath retains the more congenial temperature of 40°.

Among the experiments made by the Accademia del' Cimento, we find many details independent of those already adverted to, which are at once accurate and curious, and especially I think in that section of their *Transactions*, entitled *Experiments relating to Ice.* In the 6th experiment of this sec-

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ch'ella toccava l'acqua del ghiaccio s'osservava nell' acqua del collo un piccolo sollevamento, ma assai veloce, dopo il quale con moto assai ordinato, e di mezzana velocità s'andava retirando verso la palla, finchè arrivata a un certo grado non proseguiva più oltre a discendere, ma si fermava quivi per qualche tempo, a giudizio degli occhi, affatto priva di movimento. Poi a poco a poco si vedea ricominciare a salire, ma con un moto tardissimo, e apparentemente equabile, dal quale senz' alcun proporzionale acceleramento spiccava in un subito un furiosissimo salto, nel qual tempo era impossibile tenele dietro coll' occhio, scorrendo con quell' impeto, per così dire, in istanti le decine e le decine de' gradi. *Esperienze intorno al progresso degli artifiziali agghiacciamenti, e de' loro mirabili accidenti.* Saggi di naturali esperienze fatte nell' accademia Del Cimento."—Firenze, 1691.

tion they notice the effect of various metallic vessels upon the thawing of ice: they found it was longer preserved in lead and tin than in similar vessels of brass and of iron; and that it soon thawed in gold, and sooner in silver. This enumeration of the metals is in the inverse order of their conducting power, as was ascertained more than a century afterwards by Dr. INGENHOUSZ.

The radiation, reflection, and refraction of heat, are subjects of inquiry which also probably engaged much of the attention of the Florentine experimentalists, but their published essays contain scarcely any details relating to them. In the ninth experiment, however, of the above quoted section, they have given an account of a discovery that has recently excited much discussion, relating to the reflection and radiation of cold. "We were anxious to try if a concave mirror, placed before a mass of ice, weighing five hundred pounds, caused any reflection of cold upon a very delicate thermometer placed in its focus; and truly it began immediately to fall; but in consequence of the vicinity of the ice, it was doubtful whether the effect resulted from the direct or from the reflected rays; we, therefore, covered the mirror, and whatever was the cause, certain it is that the spirit began immediately to rise again. With all this, we do not mean positively to affirm that no other cause could have produced such an effect than the absence of the rays reflected from the mirror, for we were not careful in adopting all the precautions requisite in such an experiment *."

MUSCHENBROEK, DE MAIRAN, and others, have concluded from these and other experiments, that cold is not the mere absence of heat, but a distinct form of matter possessed of specific properties. Sometimes it has been talked of as a substance of a saline nature, floating, as in minute particles, in the air, and occasioning the congelation of water, by intruding themselves among its particles. Now, although we cannot adopt such a conclusion, which is not at all called for by the

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* Saggi above quoted. See also Waller's Translation of the Essays of the Academicians del Cimento. 1684.

phænomena, we shall presently find it plausible to conjecture that ice and other cold bodies do radiate matter, which is capable of exciting the sensation of cold in circumjacent bodies.

To get rid, however, of such an hypothesis, it has been conjectured that the effect of the ice is to disturb the balance of temperature in the surrounding bodies, and consequently to cause a chasm, as it were, into which they immediately pour their excess of heat; among these is the thermometer, which consequently indicates cold: but although such an explanation might suffice in respect to the mere approximation of the ice to the thermometer, it is lamely applicable to the case of radiation.

Sir H. Davy says, "the apparent radiation of cold is in harmony with the phænomena of the reflection of the solar beams; for if it be supposed that rays capable of producing heat emanate from all terrestrial bodies, but in quantities greater in some increasing proportion as their temperatures are higher, then the introduction of a cold body into the focus of one mirror ought to diminish the temperature of a thermometer in the focus of the other, in the same manner as a black body placed in one focus would diminish the quantity of light in the other focus; and the eye is to the rays producing light, a measure similar to that which the thermometer is to rays producing heat *."

Considering the phænomena of reflection and of radiation in general, it appears necessary to admit, that the temperature excited by radiant matter varies with its source, and that all substances must necessarily be considered as producing these emanations. If we approach a heated surface we feel the radiant heat; if the surface be of the same temperature as ordinary circumjacent bodies, or of a temperature between 40° and 80°, we feel, perhaps, nothing remarkable; yet such a surface does actually radiate matter of its own temperature, as shown by approaching it with a cooler thermometer: if the surface be of ice or colder materials, we feel upon approaching it the

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* Elements of Chemical Philosophy, p. 206.

sensation of cold, depending evidently upon the emanation of cold radiant matter, since it is susceptible of reflection by the mirrors. We are further to consider, that the terms *heat* and *cold* are merely relative. We may suppose that in an atmosphere heated to 400°, boiling water would radiate (comparatively speaking) cold; and in the same way ice at 32° would radiate heat in an atmosphere very much below the freezing point. In some late researches conducted with the æthrioscope, Professor LESLIE has shown that under certain aspects of the heavens, cold frequently radiates from the clouds to the earth, and we must all have occasionally experienced, on looking towards the sky, a sensation of cold descending upon the face.

§ VII.

FROM the preceding details some idea may be formed of the state of chemistry at the close of the seventeenth century. As an art, we have seen with what success and diligence it was cultivated by BASIL VALENTINE and GLAUBER; and how ably and eagerly it was pursued as a science by MAYOW and HOOKE. To these philosophers and to a few of their companions we not only owe the materials that were arranged and embodied by their earliest successors in the eighteenth century, but we are to ascribe also to them the merit of founding scientific chemistry; of laying the basis upon which the superstructure of modern chemical science has been raised. The importance of multiplied observations and experiments, the application of chemical principles to agriculture, and the aid to be derived from them in several arts and manufactures, as well as in many departments of domestic economy, are to be learned in the writings of GLAUBER; while BASIL VALENTINE and VAN HELMONT have shown the necessity of studying pharmacy on chemical principles, and have applied, with much success, the doctrines learned in the laboratory, to the preparation of many invaluable medicines, which have facilitated the treatment and cure of disease; nor were the quackery and eccentricities of PARACELSUS unemployed in this reformation. In that age, example was more efficacious than precept; and those who witnessed the cures which he performed, enlisted under his banner, and were equally vehement with their leader in combating the doctrines of the Galenical school of physic, and substituting those of the chemical sect.

If we look at the scientific generalizations of modern chemistry, and more especially at the theories of combustion and acidification, so diligently promulgated as original, by the French school, about the middle of the last century, we find them not anticipated merely, but even minutely explained, by BOYLE, HOOKE, and MAYOW, who flourished about an hundred years before LAVOISIER; and MAYOW, in his researches into the laws and phænomena of chemical affinity, seems to have trodden upon ground which even NEWTON explored as his own. In the history of chemistry, we perceive perhaps more than in any other branch of science, the different roads by which the human mind arrives at the same conclusions; but we are not therefore to consider those conclusions as unavailing, because anticipated; the very circumstance of attaining them by different means, justifies the search; and he whose investigations disclose new views, and unfold new truths, may rest satisfied that he has not laboured in vain, because he ultimately arrives where others have been before him. In estimating however the true merits of chemical discoveries and inventions, and more especially in determining the excellence and originality of theories, it is requisite to look to their sources, to examine the steps which lead to them, and the paths by which they are surrounded, and upon that examination to found our opinion.

The leading feature and important novelty of the science, as influencing its progress in the last century, was certainly the discovery of gaseous bodies, and the perfection of pneumatic chemistry; without which, analysis could have made little progress, and, independent of which, all improvement in theory would have been but slow and ineffectual; it was also materially, though less directly assisted by those investigations respecting the agency of heat, in which Dr. BLACK made himself so eminently conspicuous.

Though something is due to MAYOW, we must in justice confer the merit of founding pneumatic chemistry upon Dr. STEPHEN HALES*, whose researches came before the public very early in the last century. "He refused a canonry of Windsor, that he might continue to devote himself to his parochial duties and favourite scientific pursuits; and, as piety, truth, and virtue, were the principles of his character, he lived in universal esteem to the age of 84, dying at Teddington, on the 4th of January, 1761, where he was buried, under the church-tower, which he had rebuilt at his own expense."

Dr. HALES commenced the communication of his researches to the Royal Society about the year 1717, and, in 1727, he published his *Statical Essays, containing an Essay towards a Natural History of Vegetation, of use to those who are curious in the Culture and Improvement of Gardening: also a Specimen of an Attempt to analyse the Air, by a great variety of Chemico-Statical Experiments, which were read at several Meetings before the Royal Society*. In 1733, a second volume of these Essays was published, containing *Hæmastatics, and Experiments on the Stone of Kidney and Bladder*. Of these Essays, it will be first necessary to advert to the contents of those relating to the *analysis* of the air, a term, by the way, which by no means well applies to the researches they contain.

Dr. HALES employed several methods of collecting and

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* Born in Kent, 1677; died at Teddington, 1761.

examining the gaseous products of a variety of bodies, many of which approach those at present in use. Sometimes he placed substances upon a stand, under a bell-glass inverted over water; or he employed a flask to contain the materials producing aëriform matter, over which was placed a bell-glass, the whole being confined over water as before. Or where a high temperature was required for the production of the gaseous bodies, he used an iron retort formed of a bent gun-barrel, and received the air into a vessel inverted in a tub of water.

In the modification and management of these forms of apparatus, he displayed some ingenuity; but it should be remembered that he was anticipated in the greater number of his contrivances by MAYOW, as we have already had occasion to remark.

In prosecuting his inquiries by these means, Dr. HALES stumbled upon a variety of curious facts and observations; but having unluckily predetermined that the various products formed were mere modifications and contaminations of common air, he let slip a numerous series of discoveries once fairly within his grasp, and which were afterwards eagerly amassed and successfully reasoned upon by PRIESTLEY and his contemporaries.

Thus, Dr. HALES observed that phosphorus when burned, absorbed air, and produced white fumes; but he neglected any examination of the product and of the residue. He distilled air from wood, and found it fatal to animals; from Newcastle coal he obtained one-third its weight of gas; from nitre, one hundred and eighty times its bulk; and from salt of tartar urged by an intense heat, he also procured aëriform matter; but in no one instance did he examine these gaseous products with the attention that might have been expected from an experimentalist so diligent and original. He found that iron filings and oil of vitriol produced scarcely any air; but that, upon the addition of water, gas was abundantly evolved from such a mixture. Here he obtained hydrogen, but instead of stopping to examine its properties, he hastens on to irrelevant observations, and seems always eager rather to multiply experiments than to examine their results. Upon the same principle, he accurately details the quantity of air generated by distilling hogs' blood, tallow, sal ammoniac, oyster-shells, Indian wheat, pease, mustard-seed, amber, tobacco, sugar, bees' wax, and gall-stones; and yet, from such numerous experiments, he scarcely draws a single inference that deserves to be recorded.

In his experiments on respiration, Dr. HALES obtained results of such interest, that one is surprised at the coldness with which he pursued them, and the carelessness with which he drops the inquiry. Finding that a given portion of air could only be respired for a given time, and that it soon produced oppression and difficulty of breathing, in consequence, as he says, "of the gross and sulphureous vapours with which it becomes loaded," he endeavoured to discover some substance which, by absorbing those vapours, might render respired air more fit for breathing, and consequently contribute to its purification in small and crowded rooms, and other similar situations.

The apparatus which he used in these researches was sufficiently ingenious; it consisted of a bag made of bladder, with a mouth-piece so supplied with valves as to oblige the air breathed into it to traverse its whole length, before it could return to the lungs. He found that he could breathe the air contained in this apparatus to and fro, for a minute and a half; he then wetted certain diaphragms or partitions of flannel in the bag, with different liquids, and found that he was thus enabled to respire the confined air for rather a longer time; but having dipped them in a solution of highly calcined tartar, he found he could, without much inconvenience, continue the breathing for eight minutes and a half.

It is sufficiently obvious that the air was purified in this instance by the absorption of the carbonic acid, or, to use Dr. HALES's language, "of the sulphureous gross vapours;" but, unwilling as he always appears to follow up and investigate the new facts, he says, that the effect was perhaps owing to the bladder and syphon being entirely dry, or to some unheeded passage for the air through the ligatures, "neither did I care to ascertain the matter by repeated experiments, fearing I might thereby some way injure my lungs." He however weighed the diaphragms, and found that they had increased in weight about thirty grains in five minutes, making the quantity of matter absorbed by them from the expired air, amount to nineteen ounces in twenty-four hours. In other experiments, the author notices the purification of air spoiled by the burning of candles and of brimstone, by the action of calcined tartar; but he takes no pains to inquire into the specific action of the salt, and confounds it with that of saline bodies generally.

But Dr. HALES's researches, relating to the motion of sap in vegetables, are in great measure free from the objections which I have ventured to make to his other experimental inquiries, and were pursued upon a more regular and digested plan.

His first object seems to have been to ascertain the quantities of matter imbibed and perspired by plants and trees; for this purpose he grew a sunflower in soil contained in a tight box, and watering it with given weights of water, he ascertained the quantity that it daily lost by transpiration from the leaves: after stating the extent of surface of the leaves, he informs us, that its minimum of loss by that channel was sixteen ounces, and its maximum twenty-eight ounces, in a day of twelve hours.

To ascertain more particularly the influence of the leaves upon the absorption of water by the root, two branches, one with and one without leaves were put into separate glasses, containing known quantities of water. The boughs with leaves absorbed on an average from twenty to twenty-five ounces in a day, and were lighter at night than in the morning; those without leaves imbibed but one ounce, and were heavier in the evening than in the morning. This experiment led to the inference, that the ascent of the sap, and the quantity of matter absorbed from the soil, are much influenced by the leaves; "and accordingly I observe," he says, "that the leaves next adjoining to blossoms are in the spring very much expanded, when the other leaves on barren shoots are but beginning to shoot; and that all peach leaves are pretty large before the blossom goes off: and that in apples or pears, the leaves are one-third or half-grown before the blossom blows: so provident is Nature in making timely provision for the nourishing the yet embryo fruit."

A certain degree of dryness of air is requisite to promote the due transpiration by the leaves, for when too much moisture hovers about the plant, it hinders the kindly action of the leaves, whereby, says Dr. Hales, "the stagnating sap corrupts and breeds mouldy fen, which often spoils vast quantities of flourishing hop-grounds. This was the case in the year 1723, when ten or fourteen days' almost continual rain fell, about the latter half of July, after four months' dry weather; upon which the most flourishing and promising hops were all inflicted with mould or fen in their leaves and fruit, while the then poor and unpromising hops escaped and produced plenty, because they being small did not perspire so great a quantity as the others." "This rain on the then warm earth made the grass shoot out as fast as if it were in a hot-bed, and the apples grew so precipitately, that they were of a very flashy constitution, so as to rot more remarkably than has ever been remembered."

In the course of his experiments upon the transpiration of plants, and their absorbing powers, Dr. Hales endeavoured, but always without success, to alter the flavour of their fruit by causing them to imbibe various perfumes. He placed a vessel upon a divided branch of a tree, so that it might absorb any fluid contained in it. Upon filling it with camphorated spirit of wine, the whole branch of an apple-tree was killed; but, though the apples hung several weeks afterwards, no alteration of taste was perceived in them, though the smell of camphor was strong in the leaf stalks, and all other parts of the dead branch. Different perfumed waters were absorbed by fruit-trees without injuring them, but they failed to confer any peculiar flavour on the fruit.

If, as Dr. Hales's experiments seemed to show, the transpiration of plants, and the motion of the sap, as well as the absorption from the soil, depend upon the leaves, it became an interesting question to examine these points in evergreens; and he found that they absorbed less and transpired considerably less than other trees: hence, "the cedar of Libanus, and the ilex or evergreen oak, grafted on an English oak, and on a larch, were verdant all the winter, though the leaves of the oak and larch decayed, and fell off as usual; the fact being that evergreens live and thrive with very little nourishment."

Having proved that trees transpire large quantities of liquid, our author next endeavoured to collect and examine it: he caused the branches and leaves to be enclosed in flasks and retorts; he placed a large sun-flower under the head of an alembic, and thus procured "what appeared to be pure water, very slightly tainted by vegetable matter; it seemed not to differ, though obtained from different plants."

After some observations respecting the moisture and temperature of the earth, Dr. Hales proceeds with experiments to determine the force with which trees imbibe moisture, and here he obtained some striking results. He exposed the roots of a pear-tree, and cut off the end of one, half an inch diameter; the stump was cemented into the upper end of a tube twenty-six inches long, filled with water, and dipping at its lower extremity into mercury. The root imbibed the water so vigorously, that in six minutes' time the mercury rose eight inches in the tube. This experiment was made in August.

Another experiment, similarly contrived, in which a large branch of an apple-tree was used, the diameter of its transverse section being three-fourths of an inch, caused the mercury to ascend five inches in half an hour. The oozing of air-bubbles from the cut surface interfered with the rise of the fluid in these tubes, but it was observed that the mercury rose highest when the sun was clear and warm; towards evening it subsided three or four inches, and rose again the next day. It also subsided during rain. This experiment was made in May. When we consider, says Dr. HALES, that the power thus required to raise mercury twelve inches, would raise water thirteen feet eight inches, we may form some idea of the power exerted by the growing vegetable.

Dr. HALES was one of the first who noticed the influence of cutting a ring of bark off the branch of a tree, or *ringing*, as it is now technically called, upon the growth of its fruit and leaves; and instead of attributing its effect to an accumulation of sap, the juice being prevented flowing downwards in the vessels of the bark, he refers it to a less quantity of sap arising, "whence it is better digested and prepared for the nourishment of the fruit;" he combats the notion of the sap *circulating* in trees, and imagines that it is often progressive at one time, and retrograde in another, in the same vessels.

Dr. HALES concludes his vegetable statics, with an account of some experiments to prove that a considerable quantity of air is inspired by plants, and with some observations on the growth of seeds and vegetables generally; by cementing a branch, with its leaves, into a glass tube dipped in water, he observed the liquid rise in the tube, in consequence of the absorption of the confined air; and on putting a piece of the stem of a birch-tree under the receiver of an air-pump, he extracted abundance of air-bubbles from it during the exhaustion.

He refers the first growth of a seed to the absorption of moisture, which swells it, and, as he thinks, protrudes nourishment into the radicle, which soon becomes capable of absorbing moisture from the soil; the root, he says, by expanding, carries the seed-lobes upwards with the plume, where they expand into leaves, which are of such importance to the tender plume, that it perishes on their removal; which renders it probable that they do the same office to the plume that the leaves adjoining to apples, quinces, and other fruits do to them; namely, draw the sap within reach of their attraction. As the tree advances in stature the different lateral branches shoot out, "each lower order being longer than those immediately above them, not only on account of primogeniture, but also because being inserted in larger parts of the trunk, and nearer the root, they have the advantage of being served with greater plenty of sap; hence arises the beautiful parabolical figure of trees. But when trees stand thick together in woods or groves, this their natural shape is altered, because the lower lateral branches being shaded they can transpire little, and therefore drawing little nourishment they perish; but the top branches being exposed to a free drying air they transpire plentifully, and thereby drawing the sap to the top, they advance much in height; but, if when such a grove of tall trees is cut down, there be left here and there a single tree, that tree will then shoot out lateral branches; the leaves of which branches now transpiring freely, will attract plenty of sap, on which account the top, being deprived of its nourishment, usually dies."

Such are the leading objects of inquiry which engaged the attention of Dr. HALES; and, if we consider the little progress that had been previously made in pneumatic chemistry, we must allow that he much promoted that department of research: in his inquiries into the functions of vegetables he was at once original and acute, and laid the foundation of a very useful and curious series of investigations, which DUHAMEL, ANDREW KNIGHT, and others, have pursued with so much success. HALES entered into some collateral branches of investigation, the results of which are given in the *Philoso-*

phical Transactions, and are collected in the second volume of his Essays; but they are not of that importance to form any prominent feature in a general history of his discoveries.

When it is recollected that HALES wrote at the commencement of the last century, that there were then very few models of scientific composition extant that were worth copying, and that a pompous and obscure style of writing was very prevalent among his experimental contemporaries, we cannot but admire the perspicuous and unadorned manner in which he details his facts and observations: he has all the merit that in this respect belongs to BOYLE, without his diffusiveness; and a pleasing vein of sound and unaffected morality accompanies his argument, and leads him, whilst endeavouring to unveil the mysteries of nature, to direct our attention with becoming modesty to the penury of man's wisdom, when compared with the admirable adjustment of causes and effects discoverable in her lowliest works.

Contemporary with HALES was the celebrated BOERHAAVE of Leyden, a man who laid medicine and chemistry under deep obligations; the former by his successful practice and happy method of instruction; the latter, by diligently experimenting in some of its most difficult departments. "He prosecuted chemistry," says Dr. JOHNSON, "with all the ardour of a philosopher whose industry was not to be wearied, and whose love of truth was too strong to suffer him to acquiesce in the report of others."

BOERHAAVE's original chemical investigations were nearly of the same nature as those of HALES: he experimented upon the gaseous products afforded by a variety of vegetable and animal substances; he attributed the elasticity of air to its union with fire, and considered its ponderable matter as susceptible of chemical combinations. In disclosing these views, he has certainly sketched an outline of one of the modern theories of combustion; but he went no farther, and was not more successful than HALES, in discriminating between common air and the various gaseous products that resulted from some of his experiments. His writings are enumerated in chronological order, in the masterly sketch of his life, written by Dr. Johnson; " they have," says his biographer, " made all encomiums useless and vain, since no man can attentively peruse them without admiring the abilities and reverencing the virtues of the author." His only chemical work, entitled, *Elementa Chemiæ*, was first published in 1732. It contains an useful essay on the History of the Science*.

* Boerhaave was born in December 1668, at a village near Leyden. He died in September 1738. He was an eminent ornament of medicine, as well as of chemical science. His oration upon resigning the office of Governor of the University of Leyden has been justly eulogised by Johnson. (*Life of Boerhaave.*) He here declares in the strongest terms (says his eloquent biographer) in favour of experimental knowledge, and reflects with just severity upon those arrogant philosophers, who are too easily disgusted with the slow methods of obtaining true notions by frequent experiments, and who, possessed with too high an opinion of their own abilities, rather choose to consult their own imaginations than inquire into nature, and are better pleased with the charming amusement of forming hypotheses than the toilsome drudgery of making observations.

The emptiness and uncertainty of all those systems, whether venerable for their antiquity, or agreeable for their novelty, he has evidently shown; and not only declared, but proved, that we are entirely ignorant of the principles of things, and that all the knowledge we have is of such qualities alone as are discoverable by experience, or such as may be deduced from them by mathematical demonstration.

Boerhaave's contributions to physic were large and valuable. His *Elementa Chemiæ*, of which a good translation, with notes, was edited in 1753 by Dr. Shaw, he dedicated to his brother, who was intended for the medical profession, but went into the church; while Boerhaave, who originally studied divinity, relinquished it for physic and chemistry. Alluding to this circumstance, " Providence," says he, " has changed our views, and consigned you to religious duties, while I, whose talents were unequal to higher objects, am humbly content with the profession of physic."

§ VIII.

The names of Black and Bergman, with a host of others, either forgotten, or eclipsed by those eminent philosophers, occur in the division of history at which we have now arrived, and which embraces its progress between the researches of Hales and those of Priestley. Chemistry now assumed a more important and interesting aspect; the facts already collected began to be digested and arranged, and active measures were taken to embody the scattered materials that presented themselves; to ascertain their relative value; to reject those which were unimportant or useless; and to select such as deserved to be dignified with the title of standard authorities. Dr. Black's researches, of which I shall now endeavour to give a brief abstract, possess a two-fold interest, for he not merely made important contributions to the facts of the science, but also established a new theory, connected with one of the most intricate of its subjects, heat.

Dr. Joseph Black was sprung from a Scottish family, transplanted first to Ireland and then to France, where he was born in 1728, on the banks of the Garonne. When twelve years of age, he was sent for education to Belfast, and afterwards to the university of Glasgow, where he entered upon the study of Physic, under the guidance of that bright ornament of medical science, Dr. William Cullen. In 1750, he removed to Edinburgh; four years afterwards, he took the degree of Doctor of Physic; and, in 1756, published his Experiments on Magnesia, Quicklime, and some other alkaline substances, in the *Physical and Literary Essays*. In the same year Dr. Cullen having removed to Edinburgh, Dr. Black returned to Glasgow to fill the medical and chemical chair of that University, where he was received with open arms both by the classes and professors. In 1764, he brought his ideas respecting the combinations of heat with ponderable matter to perfection. Speculations upon this subject had occupied his mind during a considerable period, but the difficulties of the inquiry, and the time necessarily consumed in other professional avocations, had considerably interfered with the pursuit.

In 1766, he was appointed to the chemical chair of Edinburgh, an office which he filled with such talent, industry, and perseverance, as not only drew an immense concourse of hearers to his class, but tended to confer upon chemistry a degree of popularity and importance, which has been greatly conducive to its promotion and extension. "His discourse," says his biographer, Professor ROBISON, "was so plain and perspicuous, his illustrations by experiment so apposite, that his sentiments on any subject never could be mistaken; and his instructions were so clear of all hypothesis or conjecture, that the hearer rested on his conclusions with a confidence scarcely exceeded in matters of his own experience*." In short, Dr. BLACK, in his professorial capacity, was entitled to every praise, and he contributed most essentially to the foundation and increase of the

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* Dr. Black's character as a lecturer is given by his friend Professor Robison in the following terms:—"He endeavoured every year to render his courses more plain and familiar, and to illustrate them by a greater variety of examples in the way of experiments. No man could perform these more neatly and successfully. They were always ingeniously and judiciously contrived, clearly establishing the point in view, and never more than sufficed for this purpose. While he scorned the quackery of a showman, the simplicity, neatness, and elegance with which they were performed were truly admirable. Indeed, the *simplex munditiis* stamped every thing that he did. I think it was the unperceived operation of this impression that made Dr. Black's lectures such a treat to all his scholars. They were not only instructed, but (they knew not how) delighted; and without any effort to please, but solely by the natural emanation of a gentle and elegant mind, co-operating indeed with a most perspicuous exhibition of his sentiments, Dr. Black became a favourite lecturer; and many were induced, by the report of his students, to attend his courses, without having any particular relish for chemical knowledge, but merely in order to be pleased. This, however, contributed greatly to the extending the knowledge of Chemistry, and it became a fashionable part of the accomplishments of a gentleman."—*Preface*, p. li.

reputation which the University of Edinburgh has acquired and maintained. Nor was his private character at variance with his public excellence ; he was mild, amiable, and fond of conversation, whether serious or sportive ; and he was not above uniting to the highest philosophical attainments, most of the elegant accomplishments of life. In his advanced age he often expressed a hope that he might not linger in protracted sickness, on account of the distress which, in such cases, is suffered by attending friends ; and his death, which happened in his seventy-first year, in November, 1799, is on this account the more remarkable. He was taking some milk and water, and having the cup in his hand, when the last stroke of his pulse was to be given, had set it upon his knee, and in this attitude expired without the smallest agitation.

The writings of Black, though lamentably few, are masterpieces of scientific composition. Newton was his model, and he was the first who transferred into chemistry the severe system of inductive logic, which marks the productions of that great master of natural philosophy. " In no scientific inquiries, since the date of the *Principia* and *Optics*, do we find so great a proportion of pure ratiocination, founded upon the description of common facts, but leading to the most unexpected and important results, as in the two grand systems of Black." Averse to all hypothesis, and aware of the multitudinous facts upon which a theory that is to stand firm must be founded, Dr. Black was unwarrantably slow in the formal public disclosure of his admirable researches. His tenets were fully and freely delivered to his pupils ; but he very rarely intruded upon the public as an author ; and his achievements in the philosophy of heat are chiefly developed in his posthumous works. This silence, arising out of an over-cautious modesty which marked all his proceedings, was not favourable to the reputation of Dr. Black. Faulty and incomplete copies of his lectures were circulated among his friends and admirers, which afterwards reached the hands of those who deserved another name, and by whom they were not very honourably employed.

When Dr. BLACK first entered the precincts of chemistry, there was a busy and acute controversy respecting the cause of causticity in earths and alkalis; it was supposed by STAHL that the conversion of limestone into quicklime depended upon its absorbing certain igneous particles; by MACQUER *, MEYER †, and others, the change was referred to an acrid acid, contracted in the fire; by others to nondescript saline particles.

Dr. BLACK's notice appears to have been drawn to this inquiry, by the researches of HOFFMAN ‡, concerning the nature

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* Macquer was born at Paris in 1718, and died in 1784. He ranks among the most eminent scientific Chemists of the early part of the eighteenth century; and though involved in the errors of the Phlogistic school, he has written with much good sense and perspicuity on a variety of chemical subjects. His most celebrated works are, the *Elemens de Chimie Theorique*, Paris, 1749; and *Elemens de Chimie Pratique*, Paris, 1751. He also published a Chemical Dictionary. The following is all his information respecting the property possessed by quicklime of rendering the alkalis caustic. After describing the process, he observes, "Le but de cette operation, est de réunir avec le sel alcali fixe ce que la chaux a de salin et d'âcre." —"On le combine avec la partie la plus âcre, la plus subtile, et la plus saline de la chaux."—"Nous n'entreprendrons point ici d'expliquer pourquoi le sel alcali, que l'on combine avec la chaux, acquiert une si grande causticité. *Cette question nous paroît une des plus delicates et des plus difficiles à résoudre que nous offre la Chimie.* Elle tient à celle des propriétés alcalines de la chaux, et on ne peut guères espérer de la résoudre, que quand on aura acquis sur la nature de cette substance, beaucoup plus de lumières que nous n'en avons à présent." *Elemens de Chimie Pratique*, pp. 179, 182.

† J. F. Meyer's *Chemische versuche zur nähern erkenntniss des ungelöschten kalks; der elastischen und electrischen Materie, des allerreinsten feuerwesens, und der ursprünglichen allgemeinen säure.* Hanover, 1764. In this dissertation, though published subsequently to Black's essay, the causticity of the alkalis and lime is referred to the absorption of a principle which the author calls *Causticum*, or *Acidum pingue*. Between the years 1760 and 1772, a great variety of dissertations were published in Germany upon this question, some in support of Black's doctrine, others in favour of Meyer's hypothetical absurdities. See Gren's *Systematisches Handbuch der Gesammten Chemie.* Halle, 1794. § 437.—*Observ. Phys. Chem.*, 1722.

‡ Hoffman was the most celebrated Chemical Physician of the age. He was born at Halle in Saxony, in 1660, and died in 1742. His writings, which are voluminous, are also valuable. In 1749, they were eked out by the Genevese booksellers into nine folio volumes. The following are his leading Essays in Chemistry: *Dissertationes de Generatione Salium,—De Natura Nitri,—De Cinnabare Antimonii,—De Mirabili Sulphuris Antimonii fixati efficacia,—De Mercurio et Medicamentis Mercurialibus. Observationum Physico-Chemicarum Collectio.* Libri iii.

of magnesia: he found that when that earth was obtained by adding a mild alkali to solution of Epsom salt, it effervesced upon the addition of an acid; but that if heated red-hot, it no longer effervesced, and moreover lost considerably in weight. The same fact applied equally to lime, and led him to believe, that that substance, instead of acquiring its acrimony by the absorption of something from the fire, became caustic by the loss or expulsion of one of its elements, in consequence of being heated. He then distilled some magnesia in a retort; but finding that though it diminished considerably in weight, the only visible loss it sustained was a minute portion of water, he conceived the possibility of the escape of some gaseous matter; and, on mixing common magnesia and an acid in a proper phial, he collected a considerable quantity of a permanently elastic gaseous body: from chalk or limestone, and from the mild alkalis, he procured a similar gas, and he termed it *fixed air*.

In 1764 Dr. Macbride, of Dublin, verified and extended these researches; he found that quicklime, after having been exposed to air, acquired the property of effervescing, and, consequently, fixed air must exist in the atmosphere*. He also explained the agency of lime as a manure, and introduced some important improvements into the art of tanning.

In 1765, Dr. Brownrigg also threw out some curious hints upon the same subject: in a communication to the Royal Society, printed in the *Transactions* for that year, he remarks, "that a more intimate acquaintance with those noxious airs in mines, called *damps*, might lead to a discovery of that subtile principle of mineral waters, known by the name of their *spirit;* that the mephitic exhalations, termed *choak-damp*, he had found to be a fluid permanently elastic; and that, from various experiments, he had reason to conclude that it entered the

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* Macbride's *Experimental Essays*, 1764. The merit of this performance induced the University of Glasgow to bestow the degree of Doctor of Physic on the author. He was born in the county of Antrim in 1726, and died in 1778.

waters of Pyrmont, Spa, and others, imparting to them that pungent taste, whence they are called *acidulæ*, and likewise that volatile principle in which their virtues chiefly depend;" and in 1769, Mr. Lane remarked the solubility of iron in water impregnated with fixed air.

I shall again have occasion to revert to the nature and properties of fixed air, which has engaged much of the attention of Priestley, Lavoisier, and other celebrated men, whose labours are yet to be noticed, consequently we may proceed to Black's researches on the subject of heat; researches which are more exclusively his own, and in which he has displayed that acuteness and originality which have given his name so high a rank in the annals of chemical science.

In speaking formerly of the experiments of Boyle, and of the investigations of the Florentine Academicians, two curious circumstances respecting the temperature of thawing ice and boiling water were noticed. It was stated, that ice, during its liquefaction, retained an uniform temperature of 32°; and that water, during its ordinary ebullition, never became hotter than 212°; hence the use of those fixed points in the graduation of thermometers. We have now to examine the views which these phænomena suggested to Dr. Black, and the results that followed his inquiries into their causes and effects.

If a vessel of ice, of any very low temperature, be brought into a warm room, or placed near the fire, or over a small steadily burning lamp, a thermometer placed in it will gradually rise to 32° in the contact of the ice, and not higher, until the whole is melted. Then the temperature of the ice-cold water will begin to rise, and if the lamp be continued under the vessel, it will go on rising till it attains the temperature of 212°, when it again becomes stationary, and remains so during the whole evaporation.

It follows from such experiments, that heat is concerned in producing two series of changes: That its first effect is to thaw the ice without elevating the temperature; and that it then raises the thermometer till ebullition takes place, after which it converts the water into vapour, without elevating either its temperature or that of the vapour. Hence the following particular heads of inquiry suggested themselves:—

1. As to the absorption of heat during the conversion of solids into liquids, and of liquids into vapours.

2. As to the evolution of heat during the converse changes; namely, the condensation of vapours, and congelation of liquids.

3. As to the quantity of thermometric heat absorbed and evolved in these different cases.

The disappearance of thermometric or sensible heat alluded to in thawing ice, takes place in all corresponding cases of liquefaction; consequently, if a cold solid be mixed with a given weight of the same substance hot, and in a liquid state, the resulting temperature will not be the mean, as would have been the case if both portions had been in the liquid state, but will be considerably below it, a portion of the heat of the hotter body having been, as it were, consumed in liquefying the solid, without affecting its temperature. Thus equal parts of water at 212°, and at 32°, give on mixture the mean temperature of 122°. But equal parts of water at 212°, and of snow at 32°, give upon mixture a temperature of 52° only, the excess of heat in this instance being concerned in *liquefaction,* not in elevation of temperature.

Dr. Black considered the lost heat as equivalent to about 140° in the case of the liquefaction of ice; and among his experiments illustrative of this subject, the following may be selected as most relevant and simple:—

Two similar globular glass vessels were filled with water, which in one was afterwards frozen; and in the other cooled as nearly as possible to the same point: they were then carried into a room of a temperature of 47°, there being no other difference between them than that the one contained ice and the other water. In half an hour the vessel of water had acquired the temperature of 40°; but in the other it required ten hours and a half to melt the ice, and raise the water to 40°. Now, as the access of heat was the same in both cases, and as this was at the rate of 7° in half an hour, it follows that in twenty-one half hours, (the time required to thaw the ice and elevate the temperature of the water to 40°,) that it would have received $7° \times 21 = 147°$. The difference, therefore, between the increase of temperature in the ice, and water vessels, with equal accessions of heat, is 140°, which will express the quantity of sensible heat rendered latent by the operation of liquefaction.

As heat is thus required to convert solids into liquids, it follows, that in cases of sudden liquefaction cold will ensue; hence its production, during the solution of many saline bodies, and hence, too, the explication of the theory of freezing mixtures.

As liquefaction is a cooling process, so congelation is a process in which heat is evolved. The freezing of large masses of water is actually a heating process to the circumjacent air. In the sudden crystallization of some saline solutions heat is evolved; and water, under certain circumstances, cooled to eight or ten degrees below its freezing point, suddenly rises to 32° upon congelation.

Having thus perspicuously disposed of the theory of congelation and liquefaction, Dr. Black turned his observation to the phænomena attendant on the formation of vapour, and there he was equally happy in his inquiries *.

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* "When we heat a large quantity of a fluid in a vessel, in the ordinary manner, by setting it on a fire, we have an opportunity of observing some other phenomena which are very instructive. The fluid is gradually heated, and at last attains that temperature which it cannot pass without putting on the form of vapour. In these circumstances, we always observe that it is thrown into the violent agitation which we call boiling. This agitation continues as long as we throw in more heat, or any of the fluid remains, and its violence is proportional to the celerity with which the heat is supplied.

"Another peculiarity attends this boiling of fluids, which, when first observed, was thought very surprising. However long and violently we boil a fluid, we can-

When water is made to boil, the steam which rises from it is not hotter than the water itself, although there be a continuous influx of heat, which therefore must become latent in the steam; and consequently steam and other vapours may be regarded as compounds of liquids and heat.

To ascertain the thermometrical expression of the latent heat of steam, Dr. BLACK proceeded thus: The time required to elevate a quantity of water to its boiling point was carefully noted: the same heat was then continued till the whole had evaporated, and the time required also noted. Thus, supposing the accession of heat to have gone on above 212°, in the same ratio as below it, the temperature that the water would have acquired was estimated, whence it was inferred that the loss of heat amounted to more than 800°.

The vast evolution of heat during the condensation of steam now admitted of an explanation, and, on estimating the latent heat of steam, by condensing a given quantity in a given weight of water, it appeared to amount to between 900° and 1000°.

About the year 1774, it was observed by Dr. CULLEN [*], that

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not make it in the least hotter than when it began to boil. The thermometer always points at the same degree, namely, the vaporific point of that fluid. Hence the vaporific point of fluids is often called their boiling point.

"When these facts and appearances were first observed, they seemed surprising, and different opinions were formed with respect to the causes upon which they depend. Some thought that this agitation was occasioned by that part of the heat, which was more than the water was capable of receiving, and which forced its way through, so as to occasion the agitation of boiling; others, again, imagined that the agitation proceeded from air, which water is known to contain, and which is now expelled by the heat. Neither of these accounts, however, is just or satisfactory; the first is repugnant to all our experience in regard to heat: we have never observed it in the form of an expansive fluid like air; it pervades all bodies, and cannot be confined by any vessel, or any sort of matter; whereas, the elastic matter of boiling water can be confined by external pressure, as is evident in the experiments made with Papin's digester."

This quotation from Black's *Lectures* (vol. i. p. 153) is inserted to show the state of the argument respecting the phenomena of ebullition previous to his researches.

[*] "The chemistry of Stahl, as it was cultivated in Germany, and France, and other countries of Europe, scarcely aspired beyond the bounds within which it had

a thermometer moistened with spirit of wine or ether, sinks many degrees during the evaporation of those fluids; with ether, the thermometer may be made to fall from 60° to 0°. The cause of this is sufficiently explained by Dr. BLACK's theory; the ether and spirit readily pass into vapour, which requires a certain quantity of heat for its production: this is taken from the bodies it happens to be in contact with, as from the thermometer, or the hand; hence the cold perceived when these fluids are applied to the body, and the advantage which results from their application in cases of burns and inflammations. These circumstances led Dr. CULLEN to accelerate the evaporation of these fluids, by exposing them under the receiver of the air-pump: by placing a flask half full of ether in a tumbler of water, it was found that, during the process of exhaustion, the evaporation was so rapid from the ether in the flask, as to convert the surrounding water into ice *.

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been circumscribed by its original founder. A few important facts, indeed, were added, but they were either connected with medical preparations, or attracted attention solely as objects of curiosity. The great and tempting field of Philosophical Chemistry lay unexplored, when it was entered upon with ardour by Dr. Cullen, who first perceived its value, and whose genius and industry, had they not been turned into another channel, would, in all probability, have been crowned with the richest discoveries. But though Dr. Cullen soon abandoned his chemical pursuits for those of medicine, he was fortunate enough to have initiated into the science a man whose discoveries formed an era in chemistry, and who first struck out a new and brilliant path, which was afterwards fully laid open, and traversed with so much eclat by the British philosophers who followed his career. This fortunate pupil of Dr. Cullen was Dr. Joseph Black."—Thomson, *History of the Royal Society*, p. 468.

Dr. Cullen's fame as a promoter of chemistry has been lost in his greater celebrity as a teacher of medicine. "Chemistry," says his biographer, Dr. Anderson, "which was, before his time, a most disgusting pursuit, was, by him, rendered a study so pleasing, so easy, and so attractive, that it is now pursued by numbers as an agreeable recreation, who, but for the lights that were thrown upon it by Cullen and his pupils, would never have thought of engaging in it at all."

Cullen was born in Lanarkshire, in 1712, and died at Edinburgh in 1790.

* Dr. Cullen's paper is published in the *Physical and Literary Essays and Observations*, Edinburgh, 1756, vol. ii. It contains the details of many interesting experiments upon the production of cold, and he considers the power of fluids in this respect as nearly according to the degree of volatility in each. "If to this," says he, "we join the consideration, that the cold is made greater by whatever hastens the evaporation, and particularly that the sinking of the thermometer is

The cause of the cold thus produced by evaporation now also became apparent, since no vapour can be in any instance formed without a proportionate consumption, or disappearance, of heat; and the theory of cooling by evaporation from surfaces, as in wine and water coolers composed of porous materials; of cooling by the affusion of spirit of wine, ether, and other rapidly evaporating substances, became at once apparent. Mr. LESLIE'S experiment on the production of ice by the evaporation of water *in vacuo,* and Dr. WOLLASTON'S *Cryophorus,* beautifully illustrate these views, but it would require much more extensive consideration than we can here afford, to trace all the bearings of the highly important investigations in which the name of BLACK is concerned. There is, however, one subject connected with them, upon which it would be improper not to offer one or two remarks: Dr. BLACK, in his published Lectures, has said, " I have the pleasure of thinking, that the knowledge we have acquired concerning the nature of elastic vapour, in consequence of my fortunate observation of what happens in its formation and condensation, has contributed, in no inconsiderable degree, to the public good, by *suggesting* to my friend Mr. WATT * of Birmingham, then of Glasgow, his improvements on this engine,"—meaning the steam-engine, of which he is then speaking. We are not, however, to conclude from these lines that Dr. BLACK meant to assume any of the merit which exclusively and justly belongs to Mr. WATT; for, in the context, he gives him all praise for the originality of his invention; and, in his private correspondence, recommends him particularly to assert, clearly and fully, his sole right to the honour of the improvements of the steam-engine; and, further, in a written testimonial given by Dr. BLACK to

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greater, as the air in which the experiment is made is warmer, if dry at the same time, I think we may now conclude *that the cold produced is the effect of evaporation.*"

* Mr. Watt died on the 25th of August, 1819, at Heathfield, near Birmingham, in the 84th year of his age.

Mr. Watt, on the occasion of a trial at law in 1797, connected with a piracy of one of his inventions, after giving a brief account of it, he adds, "Mr. Watt was the sole inventor of the capital improvement and contrivance above-mentioned *."

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* This may be the proper place to show in what way the views of Dr. Black's *Theory of Latent Heat* are connected with the improvements of the steam-engine, a subject upon which I must necessarily be brief, as only in part belonging to the object of this History. The Marquess of Worcester is commonly regarded as the inventor of the steam-engine, but his claims are not well authenticated. It is true, that, among the Utopian schemes to be found in his Century of Inventions, there is a dark description of a method of raising water by steam; but we can scarcely see how this was effected, nor are there any data recorded of the success of the contrivance. Be this as it may, he who barely and obscurely hints the possibility of an undertaking cannot be regarded as forestalling him who successfully carries it into execution; and the first person who, upon decided evidence, constructed an engine for raising water by the alternate force and condensation of steam, was Captain Savary,—who also published an account of his invention in a small tract called the *Miner's Friend*. To enter into a description of this instrument would be irrelative to my present purpose; I therefore pass on to that of Newcomen, who, in 1705, obtained a patent for an improved steam-engine. It consisted of a boiler having a cylinder placed upon it, in which was a solid plunger connected by its rod with a beam and lifting pump. The plunger was elevated by the elastic force of steam admitted from the boiler. The steam-cock being closed, a small stream of cold water was suffered to run into the cylinder, by which the steam was condensed; the pressure of the atmosphere then acting upon the surface of the plunger, forced it to the bottom of the cylinder, whence it was again raised by the re-admission of steam, and so on. In 1717, Mr. Henry Beighton became an improver of the steam-engine; he was probably the first who caused the steam-cock to be opened and shut by the machinery; for a man was obliged to attend Newcomen's engine for this express purpose. A few other improvements were made by different persons, but they did not affect the general action of the engine; the steam was alternately admitted into, and condensed in the main cylinder; and although defects in its power had been noticed, their cause was unknown until 1765, when, happily for the prosperity of the arts and manufactures of this country, the subject engaged the keen ingenuity of Mr. Watt. The model of a Newcomen's engine fell into his hands to be repaired, and in this he presently observed the immense loss of steam occasioned by its admission into the cylinder just cooled for condensation; indeed, he went so far as to ascertain, by experiment, that half the steam of the boiler was thus lost. For, having constructed a boiler which showed the quantity of steam expended at every stroke of the engine, he found that it many times exceeded that which was sufficient to fill the cylinder. But the circumstance that excited his greatest surprise was, that the injection water gained infinitely more heat than if a quantity of boiling water, equal to that required to form the steam, had been added to it. It was probably in this dilemma that he consulted Dr. Black; and the explanation of the difficulty will be obvious from the facts detailed in the text. To avail himself, therefore, of the whole power of the

Mr. WATT's capital improvement above alluded to, consisted chiefly in condensing in a separate vessel, and was adopted before he had any clear notion of Dr. BLACK's investigations; or at least the main experiments upon which this improvement hinged were previously undertaken.

It must be observed here, that Mr. WATT made a variety of curious investigations upon the subject of steam, and of the capacity of bodies for heat, (a subject first inquired into by Dr. BLACK, in 1762,) in themselves highly important; but they have been obscured by the magnitude of his inventions and discoveries more immediately connected with the perfection of the steam-engine.

If the suspicion of jealousy, of want of candour, or of any deviation from the strictest veracity, could, by any possibility, attach to either of those British luminaries whose labours

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steam, it became absolutely necessary to keep up the temperature of the cylinder constantly at the boiling point of water; this he was enabled to attain, by connecting with it another vessel, exhausted of air, and immersed in cold water, into which, when communicated with the cylinder, the steam, being an elastic fluid, instantly rushes and is condensed; and, on closing its connection with the cylinder, the steam, again admitted there, now operates with full force, and suffers no further condensation. To carry off the water from the second vessel, which he calls the *condenser*, and to perpetuate the vacuum, Mr. Watt attached to it a pump, by which both the air and condensed water are removed. The engine thus altered produced the same power as one of equal dimensions on Newcomen's plan, with rather less than one-third the quantity of steam; hence was a considerable hindrance to the use of the engine materially diminished, namely, the expense of fuel. But great as was this improvement, it forms a small part of the successful achievements of Mr. Watt in this department of mechanics; he amended the apparatus for boring the cylinders, and improved every part of the working gear of the engine; and he infinitely extended its applications and utility, by applying the power of steam to produce motion round an axis; but their enumeration would lead me out of the bounds of chemistry. I, therefore, hasten to the invention which may be said to have perfected the steam-engine. Steam had hitherto only been used to force the piston down,—it was returned by a weight attached to the other end of the beam. Mr. Watt, in 1782, constructed an engine in which steam was used to elevate as well as to depress the piston, an alternate vacuum being formed above and below it, by the condenser, as before. An engine upon this plan, executed at Mr. Watt's manufactory at Soho, near Birmingham, was first employed at the Albion Mills in 1788.

An excellent sketch of the history of the steam-engine will be found in the *Edinburgh Review*, vol. xiii. p. 311.

we have been adverting to, it might be worth entering into such details as would more distinctly unfold their respective claims ; as it is, however, I trust the short allusion made to the subject, while it places the assertions of the one in their proper light, will sufficiently vindicate the exalted merit and indisputable originality of the other.

To Mr. WATT's character, in relation to the public, and as a private individual, it is more than difficult to do justice, for the combined eloquence of the different writers who have attempted it has only feebly depicted the influence of his talents upon the state of society ; and still less has it succeeded in the more difficult portraiture of the man, occupied in the ordinary duties of life, and in the unsuspecting intercourse of social converse. Such, at least, is the impression which I feel upon looking over the different biographical sketches that have lately appeared. For my own part, I consider myself as highly fortunate in having occasionally enjoyed the society, and profited by the information of one, whom, without exception, I consider as the most eminent benefactor to his country ; and I should have attempted to have gleaned from others, and from my own memory, a few particulars relative to his character, and pursuits, had I not, in looking into a production of "the Author of Waverley," discovered a sketch of his character, which leads one to lament that the same pencil is not more frequently employed in such delineations, and induces me at once to cancel all that I had collected upon the subject. "He was a man," says that writer, "whose genius discovered the means of multiplying our national resources to a degree perhaps even beyond his own stupendous powers of calculation and combination ; bringing the treasures of the abyss to the surface of the earth; giving the feeble arm of man the momentum of an Afrite ; commanding manufactures to arise, as the rod of the prophet produced water in the desert ; affording the means of dispensing with that time and tide which wait for no man, and of sailing without that wind which defied the commands and threats of

Xerxes himself. This potent commander of the elements,—this abridger of time and space,—this magician, whose cloudy machinery has produced a change on the world, the effects of which, extraordinary as they are, are perhaps only now beginning to be felt, was not only the most profound man of science, the most successful combiner of powers and calculator of numbers, as adapted to practical purposes; was not only one of the most generally well-informed, but one of the best and kindest of human beings. In his eighty-fourth year his attention was at every one's question, his information at every one's command." "No individual in his age," says another, and equally able writer, "possessed more varied and exact information. He had infinite quickness of apprehension, a prodigious memory, and a certain rectifying and methodising power of understanding, which extracted something precious out of all that was presented to it. His stores of miscellaneous knowledge were immense, and yet, less astonishing than the command he had over them. His conversation had all the charms of familiarity, with all the substantial treasures of knowledge. With this philosophical excellence of character, be it never forgotten that Mr. WATT conjoined the higher duties and more exalted attributes of sincere, but unaffected piety. Expressing his gratitude to Providence for that length of days and exemption from infirmity which rendered the evening of his life cheerful and serene, he yielded up his soul in the calmest tranquillity, and passed, without pang or struggle, from the bosom of his family to that of his God!"

§ IX.

It is not perfectly in chronological order, to proceed in the present Section to the discoveries of Dr. Priestley [*], and yet they are so numerous and important, that it will be difficult to continue the history of chemistry up to his time, without allusion to their objects and results. I shall, therefore, endeavour to give the reader some insight into the nature and bearings of his inquiries.

Dr. Priestley's entire force was directed upon Pneumatic Chemistry. We have seen what may be termed the materials for the foundation of this branch of knowledge, in the works of Mayow and Hooke; it was pursued, as we have also found, with much diligence, but, unfortunately, in rather a desultory style, by Hales; Priestley directed his attention to it with a degree of activity and skill, then peculiarly his own; and, in the number of his discoveries, left his contemporaries far in the background, while he certainly rivalled them in their interest and importance; and this is the more surprising, when we reflect that his philosophical studies seem generally to have been considered as subordinate to his more severe and serious occupations.

Dr. Priestley first turned his attention to chemistry about 1768; he used to amuse himself with experiments on fixed air, and artificial mineral waters, and one experiment, as he says, leading to another, he soon collected those materials which he laid before the Royal Society in 1772, under the title of *Observations on different Kinds of Air*. With what zeal and success he prosecuted this subject, will be seen in the sequel.

The apparatus which is now used in the chemistry of gase-

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[*] Born at Fieldhead, near Leeds, 1733; died in Pennsylvania, 1804.

ous bodies, is almost entirely of Dr. PRIESTLEY's invention. The water-trough, with its sliding shelves and moveable supports for inverted jars; the methods of subjecting animals and plants to the action of different kinds of air; the mercurio-pneumatic apparatus for collecting gases absorbable by water; the means of measuring and weighing gases, and of subjecting them to the action of electricity, are only a few of the contrivances for which we are principally indebted to Dr. PRIESTLEY; many others employed by MAYOW and HALES were by him perfected or improved.

In his earliest experiments on fixed air, and on air tainted by combustion and respiration, Dr. PRIESTLEY has announced many highly interesting and new facts; but the discovery that takes precedence of the others, and upon which his fame has been chiefly, though not quite justly, founded, is that of Oxygen Gas, or, as he termed it, Dephlogisticated Air. I say not quite justly, because its brilliancy and importance have been suffered to overshadow many of his other original investigations, of which we hear but little, though their aggregate influence upon the subsequent progress of chemistry was most direct and important; but the fact is, that Dr. PRIESTLEY having opened, as it were, a new and rich mine in the science, found therein such abundance of treasure, that he was able to do little more than bring it to the surface, where it was soon pillaged and carried off.

Dephlogisticated Air was discovered by Dr. PRIESTLEY on the 1st of August, 1774; the method of experimenting which he adopted, consisted in exposing a quantity of Red Precipitate of Mercury to the action of the sun's rays concentrated by a burning lens; the red precipitate was contained in a small flask, filled up with quicksilver, and inverted in a basin of the same metal. "I presently found," he says, "that by means of this lens, air was expelled from it very readily. Having got several times as much as the bulk of my materials, I admitted water to it, and found that it was not imbibed by it. But what surprised me more than I can well express, was, that a candle burned in this air with a remarkable vigorous flame, very much like that enlarged flame with which a candle burns in nitrous air exposed to iron or liver of sulphur; but, as I got nothing like this remarkable appearance from any kind of air besides this particular modification of nitrous air, and I knew no nitrous acid was used in the preparation of the *mercurius calcinatus*, I was utterly at a loss how to account for it*."

Red Lead, and several other substances, among which is enumerated *Nitre*, are also shown by our author to afford oxygen at a red heat; and here I may be allowed to advert to the singular sagacity displayed by HOOKE in his notions already quoted, respecting the constitution of that salt, and its nitro-aërial particles; and to remind the reader how remarkably his surmises have been verified by PRIESTLEY; for, upon turning to those pages of the *Micrographia*, in which the theory of combustion is explained, we cannot but admire the penetration with which the presence of a body possessing the qualities of oxygen is anticipated, though the experimental demonstration of its existence was not achieved till the middle of the succeeding century. To MAYOW we might pay a similar tribute of applause; but, in canvassing the supposed discoveries of LAVOISIER and his associates, a more favourable opportunity will offer of placing these matters in their true light.

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* The following paragraph, with which Dr. Priestley prefaces his account of the discovery of dephlogisticated air, presents a picture of his mind in regard to the origin of his own researches.

"The contents of this section will furnish a very striking illustration of the truth of a remark which I have more than once made in my philosophical writings, and which can hardly be too often repeated, as it tends greatly to encourage philosophical investigations; viz., that more is owing to what we call *chance*, that is, philosophically speaking, to the observation of *events arising from unknown causes*, than to any proper design or preconceived *theory* in this business. This does not appear in the works of those who write *synthetically* upon these subjects, but would, I doubt not, appear very strikingly in those who are the most celebrated for their philosophical acumen, did they write *analytically* and ingenuously." (*Exp.* and *Obs.* Vol. II. p. 103.)

The "nitrous air exposed to iron," alluded to in the above paragraph, is the gas now called Nitrous Oxide, which Dr. PRIESTLEY also discovered, though he but imperfectly investigated its properties.

The next remarkable circumstance adverted to by our author in respect to dephlogisticated air, is its action upon nitrous gas, mixed with which it occasioned a much more considerable diminution than atmospheric air; and, as the fitness of air for respiration appeared connected with the absorption thus produced, it was inferred, that it would support respiration, an inference which the Doctor soon verified, by placing a mouse in a jar of the dephlogisticated air, in which it lived half an hour, though, by previous trials, he knew that it would only live a quarter of an hour in the same bulk of atmospheric air.

In the observations connected with these experiments, Dr. PRIESTLEY enters pretty much at length into the theory of the production of dephlogisticated air; but I shall not follow him into these hypotheses, as they are not very consistent with facts, nor even plausibly applied to them: he hints, however, at several useful applications of oxygen, and especially recommends it for the production of intense heat, by directing a small jet of it upon a piece of burning charcoal.

Among the many and ingenious investigations of this Philosopher, none have produced more pleasing subjects of enquiry than those relating to the influence of vegetation upon air contaminated by combustion, respiration, and the putrefaction of animal matter.

Finding that air was not spoiled by the growth of a sprig of mint kept in it for some months, our author thought it possible that the process of vegetation might restore the air injured by burning candles; and, accordingly, on the 17th of August, 1771, he put a sprig of mint into air in which a wax candle had burned out, and, on the 27th of the same month, found that another candle burned perfectly well in it; and then, to verify the conclusion, he divided the injured air into two separate portions, putting the plant into one of them, and merely leaving the other standing over water; he never failed to find, that a candle would burn in the former, but not in the latter.

"This restoration of air," says Dr. PRIESTLEY, "I found depended upon the vegetating state of the plant; for though I kept a great number of the fresh leaves of mint in a small quantity of air in which candles had burned out, and changed them frequently for a long space of time, I could perceive no melioration in the state of the air. This remarkable effect does not depend upon anything peculiar to *mint*, for I found a quantity of this kind of air to be perfectly restored by sprigs of *balm*." Groundsel, spinach, and some other plants, were used with like effect, to show that it did not depend upon aromatic effluvia.

In Dr. PRIESTLEY's *Observations on Air infected with Animal Respiration and Putrefaction*, a multitude of other facts are adduced to demonstrate its renovation when exposed to growing vegetables, and he is thus led to the following general remarks upon the subject. "These proofs of a partial restoration of air by plants in a state of vegetation, though in a confined and unnatural situation, cannot but render it highly probable, that the injury which is continually done to the atmosphere by the respiration of such a number of animals, and the putrefaction of such masses of both vegetable and animal matter, is, in part at least, repaired by the vegetable creation; and notwithstanding the prodigious mass of air that is corrupted daily by the above-mentioned causes, yet, if we consider the immense profusion of vegetables upon the face of the earth, growing in places suited to their nature, and, consequently, at full liberty to exert all their powers, both inhaling and exhaling, it can hardly be thought but that it may be a sufficient counter-balance to it, and that the remedy is adequate to the evil *."

In the year 1778, Dr. PRIESTLEY resumed this investiga

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* PRIESTLEY *on Air*. Vol. i. p. 93. 3d Edit. 1781.

tion, and verified his main conclusions by new and satisfactory experiments; he found, however, that it was necessary for their success, that the plants should be in a state of healthy and natural vegetation, and that all plants were not equally efficacious, some indeed appearing rather to deteriorate than improve the contaminated atmosphere *. About this time, too, Dr. PRIESTLEY made the capital discovery of the evolution of oxygen by aquatic plants, growing in water containing carbonic acid; that the presence of light was necessary to this change; that in sunshine it was most rapid; that it was in great measure independent of warmth; and, lastly, that the bladders of some kinds of sea-weed (*fucus vesiculosus*), often contained air purer than the atmosphere. The renovation of the air contained in water, requisite for the respiration of fishes, was thus accounted for; and the circumstance of fishes and most other aquatic animals being unable to live for any time in pure water, though exposed to air, satisfactorily explained.

By his contrivance of receiving gaseous fluids over quicksilver, Dr. PRIESTLEY was able to collect and examine a number of new aëriform products, absorbable by water; and in

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* At the beginning of the last summer, I confined, in equal proportions of atmospheric air, as nearly as possible, equal surfaces of the leaves of spearmint, cabbage, mustard, bean, pea, and the vine. The plants were all thriving, and, during a great part of the day, were exposed to the sun. The bulk of the air, which was confined over water, was not altered either by the mint or vine leaves; the pea and bean leaves caused a slight diminution, but the air in contact with the cabbage and mustard plant was lessened by about one-fifteenth and one-sixteenth its original bulk, and it extinguished a taper, which the others did not. The duration of each experiment was 48 hours. The average of the thermometer, during the period, was 52°, and of the barometer, 29.5 inches. This is not the place to enter into any explanation of these facts, or to enlarge the account of them; they prove, however, a corroboration of Priestley's assertion, that different vegetables act very differently on the air, and may be useful in adjusting some discordant results of later experimentalists. Some plants are much more gross feeders than others, and the nature of the soil in which they grow may often be, in some degree, judged of by their flavour. Those vegetables which are of very quick and luxuriant growth, and readily susceptible of the influence of manures, affect the atmosphere more than those whose growth is comparatively slow, and whose foliage is sparing.

these inquiries he was eminently successful. Mr. CAVENDISH in endeavouring to get inflammable air from a mixture of copper and spirit of salt, obtained one that lost its elasticity on the contact of water. "I was exceedingly desirous," says Dr. PRIESTLEY, "to become acquainted with it, and therefore began by making the experiment in quicksilver, which I never failed to do in any case in which I suspected that air might either be absorbed by water, or in any other manner affected by it; and, by this means, I presently got a much more distinct idea of the nature and effects of this curious solution." He then goes on to show, that this singular gas is derived from the acid, that it is very absorbable by water, and that common Spirit of Salt is in fact an aqueous solution of it.

His next discovery in this department, was that of an alkaline air from a mixture of lime and sal-ammoniac; it also was absorbed by water, forming "volatile spirit of sal-ammoniac, much stronger than that procured by any other means." He now thought, that by adding the acid to the alkaline air, he might possibly produce a neutral air, but immediate condensation ensued, and sal-ammoniac was deposited.

What is now termed Sulphurous Acid, or by Dr. PRIESTLEY Vitriolic Acid Air, he also discovered; he obtained it in various ways, but chiefly by heating mercury with oil of vitriol; he examined many of its combinations, and inquired into its action upon a variety of bodies *.

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* The notice of this discovery enables me, by the insertion of the following extract from his *History of Vitriolic Acid Air*, to show the candour and exactness with which he acknowledges the hints, assistance, and discoveries of others:—

"My first scheme was to endeavour to get the vitriolic acid in the form of air, thinking that it would probably be easy to confine it by quicksilver, for, as to the nitrous acid, its affinity with quicksilver is so great that I despaired of being able to confine it to any purpose. I, therefore, wrote to my friend Mr. Lane to procure me a quantity of volatile vitriolic acid," &c. "Seeing Mr. Lane the winter following, he told me, that if I would only heat any oily or greasy matter with oil of vitriol, I should certainly make the very thing I wanted, viz. the volatile or sulphureous vitriolic acid; and, accordingly, I meant to have proceeded upon this hint, but was prevented from pursuing it by a variety of engagements.

"Some time after this I was in company with Lord Shelburne, at the seat of Mons.

I believe I have now enumerated the principal discoveries which Dr. Priestley may claim as original; and, in importance, they are second to none that had been previously made, and barely inferior to those that have adorned the recent progress of chemistry. We can scarcely call him the founder of Pneumatic Chemistry, after perusing the works of Hales and Black; but he achieved more in that new department of the science than any of his predecessors or contemporaries; and though on some points anticipated, his claims to originality are on others quite unequivocal. He cannot be called the discoverer of Nitrous Gas, for it is noticed by Mayow; yet, he developed its principal properties, pointed out its useful eudiometrical applications, and showed many new modes of obtaining it. He has been stigmatized as a defender of the unintelligible system of phlogiston; and he did defend it, with unpardonable pertinacity *; but when we reflect that equally erroneous theo-

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Trudaine, at Montigny, in France; where, with that generous and liberal spirit by which that nobleman is distinguished, he has a complete apparatus of philosophical instruments, with every other convenience and assistance for pursuing such philosophical inquiries as any of his numerous guests shall choose to entertain themselves with. In this agreeable retreat I met with that eminent philosopher and chemist, Mons. Montigni, Member of the Royal Academy of Sciences; and, conversing with him upon the subject, he proposed our trying to convert oil of vitriol into vapour, by boiling it on a pan of charcoal in a cracked phial. This scheme not answering our purpose, he next proposed heating it together with oil of turpentine. Accordingly, we went to work upon it, and soon produced some kind of air confined with quicksilver; but our recipient being overturned by the suddenness of the production of the air, we were not able to catch any more than the first produce, which was little else than the common air which had lodged on the surface of the liquor, and which appeared to be a little phlogisticated by its not being much affected by a mixture of nitrous air."

* Dr. Priestley's last publication is a tract, which appeared after his retirement to America in 1800. It is entitled, *The Doctrine of Phlogiston established, and that of the Composition of Water refuted.* It contains a variety of miscellaneous observations on the phlogistic and antiphlogistic theories, but it would be useless to follow the author into his unsubstantial speculations on these subjects. He has, however, thrown out some important considerations relating to his claims of originality as the discoverer of dephlogisticated air. The following paragraph appears of sufficient importance to be transcribed. "Now that I am on the subject of the *right to discoveries*, I will, as the Spaniards say, leave no ink of this kind in my inkhorn; hoping it will be the last time that I shall have any occasion to trouble the public about it. M. Lavoisier says (*Elements of Chemistry, English*

ries have been as warmly espoused in our own days by men who in no respect are to be considered as inferior to our author, we must not impeach his discernment upon so flimsy an accusation. When we consider his numerous, and, as it were, incompatible occupations; and remember the many channels into which his exertions were occasionally directed, we presently detect the source of that wavering of opinion and unsteadiness of research that his philosophical pursuits display. His experiments were almost always submitted to the public in a crude and undigested form, for he had no time to build them into theories, or to concoct them into generalizations; and it is perhaps as well that he had not, for the bent of his mind was evidently such as to shine in experiment rather than argument.

The constitution of the atmosphere was one of the many inquiries that engaged Dr. PRIESTLEY's diligence, and that was made out during the period of his activity*. In 1722, Dr. RUTHERFORD demonstrated the existence of a peculiar

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translation, p. 36), 'this species of air (meaning dephlogisticated) was discovered almost at the same time by Mr. Priestley, Mr. Scheele, and myself.' The case was this:—Having made the discovery some time before I was in Paris in 1774, I mentioned it at the table of M. Lavoisier, when most of the philosophical people in the city were present; saying, that it was a kind of air in which a candle burned much better than in common air, but I had not then given it any name. At this all the company, and M. and Madame Lavoisier as much as any, expressed great surprise; I told them I had gotten it from *precipitate per se*, and also from *red lead*. Speaking French very imperfectly, and being little acquainted with the terms of chemistry, I said *plomb rouge*, which was not understood till M. Macquer said, 'I must mean *minium*.' Mr. Scheele's discovery was certainly independent of mine, though I believe not made quite so early." P. 88.

* The ancients appear to have regarded air as an ultimate principle of matter Thus Lucretius,—

> Aera nunc igitur dicam, quid corpore toto
> Innumerabiliter privis mutatur in horas:
> Semper enim, quodquomque fluit de rebus, id omne
> Aeris in magnum fertur mare, qui nisi contra
> Corpora retribuat rebus, recreetque fluenteis,
> Omnia jam resoluta forent, et in aera vorsa,
> Haud igitur cessat gigni de rebus, et in res
> Recidere assidue, quoniam fluere omnia constat.
>
> *De Rerum Natura*, Lib. V. v. 274,

elastic fluid in atmospheric air, differing from fixed or mephitic air, and yet, like it, extinguishing flame, and unfit for respiration*. This component part of the atmosphere was, by Dr. PRIESTLEY, called Phlogisticated Air; and he showed that when mixed with nitrous gas, it suffered no diminution; but, on the contrary, that dephlogisticated air, on the same admixture in due proportions, was almost entirely absorbed over water; hence the method before noticed which he introduced, of ascertaining what was termed the goodness of atmospheric air, by the degree of absorption exhibited upon a certain admixture of nitrous gas, over water.

It was for his various discoveries, and more especially those relating to the physiology of vegetation, that the Council of the Royal Society honoured Dr. PRIESTLEY by the presentation of Sir GODFREY COPLEY's medal, on the 30th of November, 1733†.

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* Sed aer salubris et purus, non modo respiratione animali ex parte fit mephiticus sed et aliam indolis suæ mutationem inde patitur. Postquam enim omnis aer mephiticus ex eo, ope lixivii caustici secretus et abductus fuerit, qui tamen restat nullo modo salubrior inde evadit, nam quamvis nullam ex aqua calcis præcipitationem faciet, haud minus quam antea, flammam et vitam extinguit."

† Sir Godfrey Copley originally bequeathed five guineas to be given at each anniversary meeting of the Royal Society, by the determination of the President and Council, to the person who had been the author of the best paper of experimental observation for the year past. In process of time, this pecuniary reward, which could never be an important consideration to a man of enlarged and philosophical mind, however narrow his circumstances might be, was changed into the more liberal form of a gold medal, in which form it is become a truly honourable mark of distinction, and a just and laudable object of ambition. It was, no doubt, always usual with the Presidents, on the delivery of the medal, to pay some compliment to the gentleman on whom it was bestowed; but the custom of making a set speech on the occasion, and of entering into the history of that part of philosophy to which the experiment related, was first introduced by Mr. Martin Folkes. The discourses, however, which he and his successors delivered, were very short, and were only inserted in the minute books of the society; none of them had ever been printed before Sir John Pringle was raised to the chair of the society.—Chalmers's *Biographical Dictionary.—Life of Pringle.*

Dr. Franklin, in a letter upon the subject of these discoveries to Dr. Priestley, has expressed himself as follows:—

"That the vegetable creation should restore the air which is spoiled by the animal part of it, looks like a rational system, and seems to be of a piece with the rest. Thus, fire purifies water all the world over. It purifies it by distillation when it raises it in vapour, and lets it fall in rain; and farther still by filtration, Sir John Pringle, who was then President, delivered on this occasion an elaborate and elegant discourse upon the different kinds of air, in which, after expatiating upon the discoveries of his predecessors, he points out the especial merits of Priestley's investigations. In allusion to the purification of a tainted atmosphere by the growth of plants, the President has thus expressed himself:—

"From these discoveries we are assured, that no vegetable grows in vain; but that, from the oak of the forest to the grass of the field, every individual plant is serviceable to mankind; if not always distinguished by some private virtue, yet making a part of the whole which cleanses and purifies our atmosphere. In this the fragrant rose and deadly nightshade co-operate; nor is the herbage nor the woods that flourish in the most remote and unpeopled regions unprofitable to us, nor we to them, considering how constantly the winds convey to them our vitiated air, for our relief and their nourishment. And if ever these salutary gales rise to storms and hurricanes, let us still trace and revere the ways of a beneficent Being, who not fortuitously, but with design, not in wrath, but in mercy, thus

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when, keeping it fluid, it suffers that rain to percolate the earth. We knew before that putrid animal substances were converted into sweet vegetables when mixed with the earth and applied as manure; and now, it seems that the same putrid substances, mixed with the air, have a similar effect. The strong thriving state of your mint, in putrid air, seems to show that the air is mended by taking something from it, and not by adding to it. I hope this will give some check to the rage of destroying trees that grow near houses, which has accompanied our late improvements in gardening, from an opinion of their being unwholesome. I am certain, from long observation, that there is nothing unhealthy in the air of woods; for we Americans have everywhere our country habitations in the midst of woods, and no people on earth enjoy better health, or are more prolific."—*Phil. Trans.* 1772, page 199.

Notwithstanding these researches, which have exposed some very curious facts relative to the chemical physiology of plants, it must be confessed that the causes of the renovation and equality of our atmosphere are yet by no means ascertained; for, although some growing vegetables do, under certain circumstances, purify the air (by the absorption of carbon and the evolution of oxygen), yet, when in a state of decay, they invariably add to its contamination; and a general view of the subject would lead us to conclude, that vegetables produce little effect upon the general constitution of the atmosphere.

shakes the water and the air together, to bury in the deep those putrid and pestilential effluvia which the vegetables on the face of the earth had been insufficient to consume."

The chemistry of gaseous bodies, in consequence chiefly of Dr. PRIESTLEY'S investigations, now became a main branch of the science, and some of his most eminent contemporaries were equally diligent with himself in its promotion and elucidation. Among others, BERGMAN and his friend and pupil SCHEELE, may be ranked among its successful followers; and Mr. CAVENDISH lent it his powerful aid; but I have thought it better to confine myself to the abstract view of such of Dr. PRIESTLEY'S discoveries as may be strictly termed his own, than to blend them with the achievements of other philosophers, who experimented with distinct views, though occasionally treading in his footsteps.

§ X.

BERGMAN, of Sweden, was born in the year 1735, and died in 1784, in consequence, as it is said, of intense application to his studies: he was not only a very diligent traveller in the beaten paths of chemistry, but he searched the depths, and ascended the heights of the science; his life was short, but as he neither lost nor misemployed time, his activity compensated for the brevity of his days; he not only opened a new mine in his favourite science, but examined its treasures and scattered its riches, for BERGMAN invented the art of chemical analysis.

In his *Prefatory Essay on the Investigation of Truth*, this author has depicted his feelings upon the subject of experimental science, in perspicuous and unaffected terms; and a mind so directed could not but be successful in its exploits, when we remember that even in his days there were few willing entirely to throw off the presuming livery of scholastic philosophy. "A tendency," he says, "to Cartesianism still exists, and upon attentive consideration it will not appear wonderful that the human mind should delight to indulge in this method; for, on the one hand, the way of experiments is expensive, troublesome, and tedious; all minds, therefore, are not capable of enduring it; many are without the proper instruments, others want the necessary dexterity; but the most universal defect is that of patience and perseverance, so that if the experiment does not at once succeed it is abandoned in disgust. Man, in his ordinary state, seems by nature prone to indolence. On the other hand, the contemplative method favours the desire of knowledge; by pretending to unlock the secrets of nature with ease and expedition, it sooths the natural rage of explaining all things; and by supposing every thing accessible to the human intellect, administers pleasing flattery to vanity and arrogance."

It is upon the analytical talents of Bergman that I propose to dwell; it is there that he was pre-eminently original and successful, and upon that foundation his character as a chemist may safely be built.

The use of tests for the discovery of certain substances held in aqueous and other solutions, is first particularly dwelt upon by Boyle, and he was sometimes very fortunate in their contrivance and applications. He noticed the conversion of certain vegetable blues to red by acids, and to green by alkalis; the cloudiness produced by common salt in solution of silver, and the discoloration by liver of sulphur; and several other circumstances connected with the detection of certain principles, by chemical re-agents.

In 1667, Du Clos undertook an examination of the waters of France; and in 1686, Hierne published some clever experiments upon the same subject in Sweden. In these writers the use of galls for the detection of iron is alluded to, and the necessity pointed out of examining the residuary product of evaporation.

In 1726 and 1729, Boulduc used spirit of wine to precipitate certain saline bodies insoluble in that menstruum. In 1755, Venel pointed out the existence of fixed air in the waters of Seltzer, Spa, and Pyrmont; Lane, in 1769*, shewed the method of imitating chalybeate springs; and in 1722, Dr. Priestley published directions for saturating water with fixed air.

Bergman, in his *Essay on Mineral Waters*, after adverting to a variety of circumstances relating to their general characters and sources, proceeds to point out, in the seventh section, the principal re-agents and precipitants, useful in their examination, and to describe the nature of their changes, and indications, with useful precision, in the following order:—

A. Infusion of litmus, or turnsole, is so delicate a test for the acids, that a single grain of sulphuric acid reddens 408 cubic inches of the blue tincture.

Paper, dipped in this tincture, and reddened by distilled vinegar, has its blue colour restored by alkalis: but the tincture is more sensible than the paper, for the latter is not reddened by aërial acid (fixed air); yet one part of water saturated with aërial acid, renders fifty parts of the infusion red.

B. Tincture of Brazil-wood becomes blue by alkalis, and is sensible to less than one grain of crystallized soda in 4000 of water.

C. Turmeric, either on paper, or in watery tincture, is a good, but less sensible, test for alkalis, which render it brown.

D. Tincture of galls discovers iron by a purple or black cloud.

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* Mr. Lane was the first who ascertained the solubility of iron in water, impregnated with fixed air.—*Phil. Trans.* 1769. "By this means," says Sir John Pringle in his discourse on the different kinds of air, delivered at the anniversary meeting of the Royal Society, November 30, 1773, "the nature of the metallic principle in mineral waters was clearly explained, and the whole analysis of those celebrated fountains, so often attempted by chemists and others, and still eluding their laboured researches, was thus, in the most simple manner, brought to light."

E. Prussiate of potash produces a blue tinge in water containing a minute portion of iron; it also precipitates other metals; copper, brown; manganese, white.

F. Sulphuric acid forms a white precipitate in all solutions containing baryta. If it produce bubbles, it indicates some combination of aërial acid. Nitric acid is highly useful for showing the presence of sulphur, which it precipitates from all hepatic waters.

G. Oxalic acid detects the minutest quantity of lime, by producing a white cloud, either immediately or after some hours. This test shows that scarcely any water is free from lime; and the purest, within twenty-four hours, deposits a portion of oxalate of lime, although sometimes so sparingly as to escape observation, unless lines be drawn on the bottom of the vessel with a glass rod, in the direction of which the precipitate attaches itself.

H. Aërated fixed alkali throws down the metals and earths; if the substance be easily soluble in aërial acid, the caustic alkali may be used.

I. Aërated volatile alkali also throws down earths and metals, and is an excellent test for the presence of copper, which it indicates by a blue colour, more or less intense according to the quantity of alkali added.

K. Lime-water detects aërial acid, by a precipitate of aërated lime.

L. Muriate of baryta forms an insoluble white precipitate in water containing any soluble vitriolic salt; twelve grains of crystallized Glauber's salt, dissolved in a kanne of distilled water (about three quarts), immediately exhibits white striæ on the application of this test. Even one grain in the kanne exhibits a white cloud after some hours, and as it only contains 0.26 grains of sulphuric acid, we may judge of the nicety of this precipitant, which even exceeds turnsole itself in sensibility.

M. Muriate of lime may be used for the detection of fixed alkali, but it is an ambiguous test, because if sulphate of magnesia be present, it produces gypsum.

N. Solution of alum is also of little use, though occasionally employed as a test for alkalis.

O. Nitrate of silver is a certain and delicate indicator of muriatic acid and its combinations. A grain of common salt, in a kanne of water, is instantly rendered evident by white streaks. Under some circumstances it may also form a precipitate with sulphuric acid, but sulphate of silver is much more soluble than muriate; thus, no visible turbidness arises, unless the kanne of water contains ninety-eight grains of Glauber's salt, or twenty-five of vitriolic acid. The presence of hepatic air renders the precipitate of silver more or less brown. Alkalis, lime, and magnesia, also precipitate nitrate of silver.

P. Nitrate of mercury is a prevaricating test, but very sensible to a variety of substances that may exist in mineral waters. As BERGMAN has not pointed out any particular application, in which this salt is essential, it will not be necessary to follow up his remarks on it, though in other respects important.

Q. Corrosive sublimate;

R. Acetate of lead;

S. Sulphate of iron; and,

T. White arsenic are next enumerated, but their utility is dubious, and the observations upon them of little value to the analyst.

U. Spirituous solution of soap is useful in giving general indications of the purity of water, which, if pure, scarcely renders it opalescent; but, if abounding in foreign materials, or *hard* and unfit for washing, it produces more or less opacity or precipitation.

X. Liver of sulphur is affected by so many causes, that it may be dispensed with in the examination of waters.

Y. Alcohol throws down such salts as it cannot dissolve, especially the sulphates. It dissolves many muriates and nitrates.

I have thus enumerated the tests recommended by BERGMAN, and given an abridged account of his remarks upon them, for the purpose of showing the rapid progress which, under his assistance, was made in analytical chemistry: it is true that of many of these re-agents and of their applications he was not the original inventor; but he was the first who showed the real value and the limits of the indications which they afford,—an effort of no common sagacity, when we revert to the state of chemistry in his time.

Proceeding with the analysis of mineral waters, BERGMAN next adverts to their gaseous contents, which may be expelled by heating a given portion of the water in a retort, the beak of which is plunged into the mercurio-pneumatic apparatus, and the gas secured in the usual way. It commonly consists of pure air and aërial acid; the latter may be absorbed by lime-water. The presence of hepatic air is easily recognised by its fetor.

The remaining water is directed to be evaporated to dryness, and the residue weighed and digested in pure alcohol; the residue, insoluble in alcohol, is then to be shaken with eight parts of cold water; and finally, the matters which resist the action of alcohol and cold water are to be boiled in four or five hundred parts of distilled water, and the solution filtered. The ultimate residuum generally contains iron and carbonate of lime, or perhaps of magnesia, previously suspended by carbonic acid; it may be in afew instances argillaceous or siliceous, and perhaps contain manganese, and directions are given at length for its separate analysis, as well as that of the aqueous and alcoholic solutions. It is here that BERGMAN displays an ingenuity and accuracy then new to chemical science, for, in measuring his merits by a true estimate, we must go back to the state of chemistry at his time, and divest ourselves of its modern perfections and refinements; then the peculiar and genuine character of his researches will become prominent.

Having, in the paper of which I have given an outline, described the general principles of the analysis of mineral waters, BERGMAN proceeds, in several following essays, to apply them to individual analyses, and his dissertations on the waters and acidulous spring of Upsal, on sea-water, and on the artificial preparation of hot and cold medicated waters, each exhibit proofs of his skill as an analyst, and accuracy as an experimenter; but, although these and his other detached essays are excellent in their way, we must here pass them by, in order to examine such of his contributions as tended to the general improvement and extension of chemical science; among these, his luminous dissertation on chemical attraction*, already adverted to, is pre-eminent, and the twenty-fourth essay in the second volume of his *Opuscula*, entitled *De Minerarum Docimasia Humida* (on the Art of Assaying in the Humid Way), must be considered as the parent source of that branch of analytical chemistry so successfully followed up, though upon a limited scale, by SCHEELE, and in the improvement and extension of which KLAPROTH passed his long and laborious life.

It must be premised, that the assay or analysis of minerals had, with the exception of the experiments of MARGRAAF †,

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* De Præcipitatis Metallicis.

† Among those whose names became eminent in the history of chemical science during the first half of the eighteenth century, Margraaf is entitled to particular mention. He was born at Berlin in 1709, where he died in 1782. He was a pupil of the once celebrated Neumann, a man whose works are now not much thought of, but who did considerable service to the chemistry of his day, and was evidently possessed of great diligence and some capacity. Casper Neumann was born at Zullichau in Prussia, in 1682, and in 1705 we find him enjoying the patronage of the King of Prussia, by whom he was sent to complete his studies at the University of Halle. In 1711 he became a pupil of Boerhaave, and shortly after visited England, whence he accompanied George I. to Hanover in 1716. In 1723 he became Professor of Practical Chemistry in the Royal College of Berlin, where he died in 1737. His works consist chiefly in dissertations on various subjects of chemical inquiry, published in the *Transactions of the Royal Society*, and in the *Miscellanea Berolinensia*. His Lectures were not printed till after his

hitherto been confined to certain operations effected by the aid of fire, in which, except in common and obvious cases, their nature was rather guessed at than demonstrated. This art had its origin in the sixteenth century; and in 1576 the celebrated work of **Agricola** brought before the Public all that was important in relation to it, describing the instruments and processes with scrupulous and minute accuracy, and illustrating them by a curious collection of cuts. **Agricola** was succeeded by **Lazarus Erckern**, whose work on the docimastic art is much eulogized by **Boerhaave**. In the above-named essay **Bergman** points out the fallacies and imperfections to which igneous analysis is liable, and dwells upon the advantage of operating in the humid way, that is, by solvents and precipitants. He then proceeds to separate examinations of various metallic ores, as illustrations of his new method. Many of the conclusions and reasonings contained in this essay are founded upon the details of the preceding one on Metallic Precipitates. "He," says our author, "who first saw the corrosion of a metal by a limpid liquid, who beheld the opaque and ponderous body gradually disappear, and become a part of a transparent, and apparently homogeneous fluid, and who saw the same metal re-appear upon the addition of a proper precipitant, must have been infinitely surprised, and struck with admiration of the occult powers of nature. But because we are accustomed to these phenomena, we neglect inquiring into their causes, though of the utmost importance,

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death, and proved a valuable magazine of chemical knowledge. "The author," says Dr. Lewis, who edited his works, "biassed by no theory, and attached to no opinions, has inquired by experiment into the proportions and uses of the most considerable natural and artificial productions, and the preparations of the principal commodities which depend on chemistry, and seems to have candidly and without reserve communicated all he discovered." In 1733, Margraaf pursued chemistry under Juncker at Halle, and, having returned to Berlin in 1738, we find several of his contributions in the *Transactions of the Scientific Society* of that capital. Subsequent to that period, his works were collected and published at Paris in 1762. They contain a great body of information, at that time novel and important, but they are chiefly entitled to notice as furnishing specimens of the art of analysis.

as forming the entire basis of practical chemistry. Such phenomena are so varied and intricate, that volumes would be insufficient for their complete discussion; so that I propose to limit my observations to the separation of metals from acids, and to the particular consideration *of the weights of the precipitates*." Then, after a luminous summary of the general phenomena of the solution of metals, he advances a series of facts relating to their precipitation; he shows that the caustic fixed alkalis occasion precipitates of the *calces*, but loaded with water, by which their weight is much increased: that carbonated alkali precipitates carbonated oxides by double decomposition: that certain acids, which form insoluble compounds with metals, throw them down from their soluble compounds: that certain salts act in the same way by double elective attraction; and that in some cases triple combinations ensue, as when platina is precipitated by sal ammoniac. He then adverts to the decomposition of one metallic salt by another, even where the acid is the same in both. Thus, sulphate of iron and muriate of tin decompose muriate of gold. The metals also precipitate one another after a certain order, which is the same in all acid solvents, and effected by double elective attraction, "for the metal to be precipitated exists in the solution in a calcined state, but being reduced by the phlogiston of the precipitant, falls to the bottom; while the precipitant, being calcined, becomes soluble. Although," he says, "many anomalous circumstances occur in this matter, the order is constant and never inverted." The fifth section of this paper explains the use of tests for discriminating the metals, pointing out the colours of metallic precipitates. "Gold and platinum are only in part separated from acids by the alkalis. Nitrate of silver affords a brown precipitate with caustic, and a white with aërated soda and with muriatic acid. Solution of muriate of mercury gives a red precipitate with carbonated, and a yellowish, or orange, with caustic alkali. The latter is black, if the solution be prepared without heat.

Nitrate of lead is precipitated white by caustic alkali, an excess of which redissolves the precipitate. Nitrate of copper gives a bright green compound with aërated, and brown with phlogisticated alkali (ferro-prussiate of potassa). Iron is thrown down green by aërated alkali, and the precipitate, on exsiccation, becomes brownish yellow. Tin gives a white cloud with all the alkalis; bismuth, white with water and alkalis; nickel, greenish-white with alkalis and ferro-prussiate of potassa; zinc and antimony white with all alkalis."

Such is a short abstract of the contents of this section, which, although obscured by the language of the old school, and therefore scarcely, perhaps, intelligible to the chemical student of the present day, abounds in useful and perspicuous details: it is followed by the concluding section, containing a table of the relative weights of precipitates, procured in different ways, from a solution of one hundred parts of metals; and, as Bergman observes, "this table, upon proper examination, reveals many mysteries." It seems to have been the general opinion at this period, that the relative weights of precipitates were in all cases the same; that is, that one hundred parts of lead, for instance, dissolved by nitric acid, and precipitated by caustic, aërated, and phlogisticated alkali, and by sulphuric acid, furnished an equal weight of precipitate in each individual instance. Our author here shows the fallacy of this opinion, and demonstrates the difference of weights to depend upon the different proportions of the precipitant contained in the precipitate, and upon the occasional retention of a portion of the solvent. The list of precipitates annexed to this paper will disclose to the attentive observer, principles analogous to those exhibited by the tables of Richter, and upon which one of the main pillars of the theory of definite proportions may be said to rest.

Bergman's essay on fixed air, or, as he has chosen to call it, *aërial acid*, is the last of which I shall make any particular mention. His chief experiments on this subject were probably made about the year 1770. The dissertation I am now quoting was read in 1774 before the Royal Society of Sciences at Upsal, and is printed in their Transactions for 1775. After describing the several methods of obtaining fixed air by the action of acids upon carbonates, by submitting them to a red heat, and by fermentation, he proceeds to define the meaning of the word *acid*, in order to show that fixed air belongs to that class of bodies; that it is soluble in water, that it has a sour taste, reddens turnsole, and unites to and forms crystallizable compounds with alkalis, destroying at the same time their causticity.

He detected this acid in the *marmor metallicum* of CRONSTEDT (carbonate of baryta), and observed the rapidity with which baryta water absorbs carbonic acid from the air, forming an effervescent precipitate. Speaking of the action of carbonic acid upon lime, he gives a masterly sketch of the principal facts relating to the composition and decomposition of the carbonate of lime: he shows the solubility of calcareous spar, in water impregnated with fixed air, and its subsequent deposition, often in small crystals; and the same property is also proved to belong to magnesia. BERGMAN then goes on to discuss the elective attractions of fixed air, of which he gives the following Table:—

AERIAL ACID.

Pure terra ponderosa.
—— lime.
—— fixed vegetable alkali.
—— fixed mineral alkali.
—— magnesia.
—— volatile alkali.
Zinc.
Manganese.
Iron.

He says it appears to be the weakest acid known, for it is expelled not only by vinegar, but by the phlogisticated acid of nitre and vitriol (nitrous and sulphurous acids); yet he observes that acetate of lead is decomposed by carbonic acid, which appears an anomaly, and suggests a question which he leaves undecided till experiment shall have enabled him to explain it. The acid properties of fixed air are next dwelt upon, and the probability of its acidity resulting from foreign matter negatived; for when "rightly depurated, though extricated by the most different means from the most different materials, whether by fire, or by solution, it is nevertheless always the same, and always acid. I conclude, therefore, with all the certainty attainable in physics, that acidity is a property essential to that elastic fluid." From the imperfection of apparatus, BERGMAN erred a good deal in calculating the specific gravity of fixed air; he, however, proved it heavier than atmospheric air, and thence accounts for its lodging in low situations, as in pits and grots; it is also shown to extinguish flame.

The essays which I have now quoted, and which may be taken as a fair sample of his method of investigation, exhibit BERGMAN in the light of a true philosopher, employing hypothesis as the precursor and not the substitute of experiment; countenancing no theory but such as admits of rigid demonstration; advancing no favourite doctrines nor hasty speculations; but always the candid narrator of facts. As the repeater of the experiments of others, he measures and weighs their conclusions, and assigns them their proper place in the history of science. When in the character of an original inquirer, he kindles the torch of experiment, and never advances beyond the bounds of its illumination. He seems profoundly to have admired Newton, and to have endeavoured to transfuse his methods of investigation into chemistry. "That illustrious personage," he says, "having solicitously accumulated facts, examined them with accuracy, and compared them with acuteness; from effects he advances to causes, and thence deduces the laws of the creation. His progress, though slow, is certain; and his method, though tedious, is continually unveiling the mysteries of nature. An edifice thus constructed acquires firmness by elevation, for its foundations are solid and permanent."

There is more method in Bergman than in any antecedent chemical writer; his researches appear always to have been made with an object in view; and there is an unity of design in his philosophical papers, which pleasingly distinguishes them from the undigested chaos of experiments and observations which we are obliged to wade through in preceding authors.

§ XI.

Bergman was followed by two great and contemporary luminaries of chemical science, Cavendish * and Scheele, and though each attained the goal of distinction, they reached it by very different roads; showing the little influence of external circumstances upon the growth of inherent and vigorous genius. The former was a leading person in the scientific circles of London; of noble family, and princely affluence. The latter, of humble origin, and with limited means, made up for the deficiencies of place and fortune by zeal and economy, and, in the retirement of a Swedish village, raised a reputation that soon extended itself over Europe. In private life, Cavendish was unambitious, unassuming, bashful, and reserved; he was peevishly impatient of the inconveniences of eminence; he detested flattery, and was uneasy under merited praise: he therefore shunned general society, and was only familiar in a very limited circle of friends. Here he bore his great faculties always meekly; his conversation was lively, varied, and instructive; upon all subjects of science he was at once luminous and profound, and in discussion wonderfully acute.

* Born in London, 1731; died at Clapham, 1810.

Mr. Cavendish made two capital discoveries; one of which, that of the composition of nitric acid, has already been adverted to, and arose out of his incomparable researches on hydrogen, and on the products of its combustion, which terminated in ascertaining the composition of water.

Mr. Cavendish's first communication to the Royal Society relates to the analysis of the waters of Rathbone Place, and contains nothing worthy of particular notice.

In 1776, he presented the same learned body with a dissertation on Inflammable, Fixed, and Nitrous Air, printed in the *Philosophical Transactions* for the same year, and full of important and original matter. Though his observations on fixed and on nitrous air were highly valuable, he had here been anticipated in some respects, and contemporary chemists were on most points his successful rivals; but his investigations relating to the properties of hydrogen were entirely his own; for, although it was known to others that that gas was generated by the action of certain acids on certain metals, though Mayow had collected it, and Hales proved its combustibility, it may safely be asserted, that the phenomena of its production had entirely escaped attention, and that its principal properties were previously unknown. Mr. Cavendish shows that different metals afford different quantities of hydrogen; thus zinc yielded more than iron, and iron more than tin; and further, that the state of dilution and quantity of the acid, provided there was enough to dissolve the metal, did not affect either the quantity or properties of the air. In examining its properties our author observed that it extinguished flame, destroyed animal life, and burned when pure with a pale blue flame: he determined its specific gravity, and found it was the lightest of all ponderable matter; hence its subsequent suggestion by Dr. Black and Mr. Cavallo as a substitute for rarefied air in the balloon: the former indeed failed in its application, and the latter only succeeded in the pretty experiment of elevating soap bubbles by inflating them with hydrogen: he tried bladders, but the thinnest were too heavy, and tissue paper was permeable to the gas; it is singular he did not think of gold-beaters' skin, which, for similar purposes, had been recommended two centuries before by SCALIGER the grammarian *.

The first ascent in a balloon filled with hydrogen was made on the 1st of December, 1783, by Messrs. CHARLES and ROBERT, at Paris. In an hour and three-quarters, they alighted on the meadow of Nesle, twenty-five miles from the metropolis, and finding that the silk globe still retained great buoyant power, M. CHARLES ventured alone upon a second ascent. The sun had set, and the shades of evening were gradually condensing into the darkness of night; but his courage was rewarded by a most novel and sublime spectacle. He shot upwards with such celerity as to have attained the height of two miles in about ten minutes. The sun rose again to him in full orb, and from his lofty station he contemplated the fading luminary, and watched its parting beams till it once more sunk below the horizon. The vapours rising from the earth collected into clouds, and veiled it from his sight, while the pale rays of the moon scattered gleams of various hues over their fantastic and changing forms. The region in which the aëronaut now hovered was extremely cold; the balloon appeared fully distended, and upon opening the valve, the gas rushed out like a misty vapour into the external air. Prudence forbade this bold voyager to remain longer in such a situation; slowly therefore descending, he alighted in safety near the forest of Tour du Lay, having travelled about nine miles in thirty-five minutes. The barometer at the greatest elevation fell to 20.05 inches, and the thermometer sunk to 21° Fahrenheit; he therefore appears to have ascended to about 9,700 feet above the level of the sea.

The balloon has unfortunately proved but an abortive instrument in the hands of science. Messrs. BIOT and GAY-LUSSAC embarked from Paris on the 23d of August, 1804,

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* Supplement to Encyclopædia Britannica. *Art.* Aeronautics.

upon an aërial excursion devoted entirely to scientific inquiry. At the height of 13,000 feet, no peculiarity appeared to attach to electric or magnetic phenomena. On the 5th of the following September, Gay-Lussac undertook a second voyage alone, and attained the enormous height of 23,040 feet above the sea. Here he experienced excessive cold; his breathing was oppressed, and the pulse quickened; he, however, did not suffer the peril of his situation, or the peculiarities of his sensations, to distract his attention, and made several magnetic, electric, and hygrometric observations, without either novel or interesting results. Having alighted in safety in the neighbourhood of Rouen, he returned to Paris, and in the presence of M. Thenard analyzed the air brought from the upper regions, which proved analogous in composition to that at the surface of the earth.

To return to Mr. Cavendish: having determined the specific gravity, and other abstract properties of hydrogen gas, he proceeded to examine the results of its combustion, and found that, when mixed in certain proportions with atmospheric air, it exploded on the contact of flame, and deposited moisture in the vessel used for the experiment, a circumstance first noticed by Macquer in 1766, and referred by Mr. Watt to the production of water in 1783. The experimental proofs, however, were still wanting, and were supplied with a masterly hand by Mr. Cavendish, in a paper given to the Royal Society in 1784. He found that a stream of pure hydrogen, burned either in air or oxygen, produced a vapour condensible into pure water. The same product resulted from the rapid combustion of a mixture of inflammable and dephlogisticated airs (oxygen and hydrogen gases). These experiments were subsequently verified by analytical researches: water was decomposed by Lavoisier, by passing steam through a red hot tube containing iron, which absorbs its oxygen, and pure hydrogen is liberated in the gaseous form. The decomposing energies of electricity have also been applied to this fluid, and it is found uniformly to be resolved into one volume of oxygen and two of hydrogen, which disappear on passing an electric spark through the mixture, and are converted into their weight of pure water.

The discovery of the composition of water was a great step in chemical science, for it developed the hidden cause of many important phenomena of art and nature: no wonder, then, that the attention of theorists was especially fixed upon it, some applying it to the explication of all difficulties; others rejecting even legitimate conclusions, and unwilling to strike this favourite element from the list of simple bodies.

Cavendish was an enemy to the new Nomenclature of chemistry, and was fond of foretelling its downfall; he disliked all innovations that were not rendered absolutely necessary by the progress of experiment, and would never adopt new opinions till fully and leisurely convinced of the fallacy of old ones. Though occasionally in his company, I scarcely ever knew him take a part of a continued dialogue, except at the Royal Society Club, where he dined every Thursday till within a short time of his death; and there he never spoke except to gain or give information.

While Priestley and Cavendish were contributing to the chemical eminence of Britain, Scheele * was diligently employed in the same pursuit under the patronage and guidance of Bergman, of whom it has been emphatically said, "that

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* Scheele is among the fortunate few, who, starting from an obscure original, have attained the zenith of scientific eminence. He was born in 1742 at Stralsund, where his father was a tradesman. His youthful days were passed in the house of an apothecary at Gottenburgh, where, by singular perseverance, and that kind of industry which is prompted by strong natural inclination, he acquired a valuable stock of chemical information. In 1773, having removed to Upsal, accident brought him acquainted with Bergman, who became his friend and patron, and to whose honour be it told, that, when Scheele's reputation afterwards rose to such a height as threatened to eclipse his own, instead of listening to the voice of jealousy, which, on such occasions, is too common a frailty, he became more zealous in behalf of his rival, and more indefatigable in the service of his friend. Scheele afterwards removed to Köping, in the neighbourhood of Stockholm, where he died in 1786.

his greatest discovery was the discovery of Scheele," for he was the first to remark his promising genius and rising merit.

Scheele's publication, entitled *Chemical Observations and Experiments on Air and Fire,* is prefaced by an Introduction from the pen of his patron Bergman, setting forth the advantages of experimental science, and the probable benefits that may result from the application of chemistry to the treatment and cure of diseases.

Finding air necessary for the production of fire, Scheele first turned his attention to its analysis: he found, that solution of liver of sulphur, and certain other sulphureous compounds, occasioned a diminution in the bulk of air to which they were exposed, equal to one part in about five; the flame of hydrogen, and that of sulphur, caused a similar decrease of bulk in air standing over water, and lime-water not being rendered in either case turbid by the residuum, no fixed air was formed. He then obtains Empyreal Air, (oxygen,) by the decomposition of nitric acid, and other processes; describes the method of transferring, collecting, and examining the gases; and endeavours to prove that heat is acompound of empyreal air and phlogiston: he also shows, by a direct experiment, that the absorption occasioned in atmospheric air by liver of sulphur is referable to the abstraction of its empyreal portion; that it totally absorbs empyreal air; and that upon adding to the residuary portion of atmospheric air a quantity of empyreal air, equal to that absorbed by the sulphurous liquor, an air is again compounded, similar in all respects to that of the atmosphere. The identity of these investigations with those of Priestley will not fail of being observed; but it must be recollected that they were entirely independent, and that although Priestley was in the field a little before him, Scheele was unacquainted with his proceedings.

The details concerning the nature of air are followed by an inquiry into the properties of Heat and Light, which, though a little tainted by false theory, bears the stamp of an able and original mind. Adverting to the reflection of the rays from a common fire, by a concave metallic mirror, he remarks, that they passed in straight lines, without suffering any derangement from currents or undulations in the atmosphere which they traverse; that glass intercepts the heat, but not the light; that a mirror of glass reflects the light, but absorbs the heat, whereas metal reflects both: the metal, therefore, if clean, does not become heated; but, if blackened over a burning candle, it then absorbs heat, and becomes very warm. He notices the distinction between heated air and heat emanating in straight lines: "represent to yourself a little hillock of burning coals; in this case, the heat darting from this hillock all around is that which may be reflected by a metallic polished plate; that, on the contrary, which rises upwards, and may be driven by winds to and fro, unites with air. I call the first kind, by way of distinction, *radiant heat*." Discussing the phenomena of solar and terrestrial radiation, he considers their apparent differences to result, not from any absolute difference in the nature of the emanating principles, but in their quantity. "There is no doubt," he says, "about the light of the sun and that of a burning candle being the same thing; for this affects the eye in the same manner as the sun, and represents the same colours through the prism, but being weaker, it is no wonder that its beams collected in a burning-glass will not burn: nor is there any doubt about light being a body in the same manner as heat, but I cannot persuade myself that light and heat are the same thing, since experiment proves the contrary."

Finding that light blackened nitrate of silver, though heat alone had no effect upon it, he considers light as containing an inflammable principle, and shows that *luna cornea*, after long exposure to the sun's rays, is no longer perfectly soluble in ammonia, but leaves a portion of reduced silver: he also shows, that when put into water, it forms muriatic acid in the light, but not in the dark; and that the violet rays produce these effects more rapidly and powerfully than the other coloured rays, and even than white light.

Among these experiments on air and fire some curious facts are detailed, respecting the spontaneously inflammable compound discovered early in the last century by HOMBERG, and called *Pyrophorus;* it is shown that potash is necessary to its formation, and that alum crystallized by ammonia is unfit for its production. The evolution of hydrogen during the action of iron upon sulphur; and of nitrogen, in the detonation of fulminating gold, are also among the facts contained in this essay; as well as a variety of curious circumstances relating to the effect of vegetation and respiration upon air; and it closes with an account of the properties of Sulphuretted Hydrogen.

Exclusive of the experimental details, there is little to praise in the *Treatise on Air and Fire,* for the theories which it contains are often strained and illicit, and do not easily admit of being rendered intelligible by the translation of the phlogistic language into that of the modern school: nor are SCHEELE's detached essays altogether free from similar blemishes; but then they are so rich in facts, that we the more easily overlook theoretical failings. His dissertation on Manganese, for instance, with a description of the principal salts of that metal, contains the important discovery of Dephlogisticated Muriatic Acid, or, as it is now termed, Chlorine; and his views respecting it, and the nature of the muriatic acid, are remarkably correct, and perfectly intelligible in present theory, if we substitute hydrogen for phlogiston; it will then be found that muriatic acid is regenerated by the addition of hydrogen to chlorine, and that hydrogen is evolved by the abstraction of chlorine from muriatic acid.

BERTHOLLET's hypothesis of the nature of chlorine for a time superseded the theory of SCHEELE, and under the name of Oxymuriatic Acid it was regarded as a compound of oxygen and muriatic acid; but, in 1811, Sir H. DAVY, in an important dissertation on the subject, published in the *Philosophical Transactions,* demonstrated the errors of the French school, revived the doctrine of Scheele, and established it by a body of evidence now generally received.

In his essays on Fluor Spar, and its acid, Scheele has committed several errors, among which the most glaring is the conclusion which he draws respecting the formation of siliceous earth. When powdered fluor spar is distilled with sulphuric acid in a glass retort, the siliceous earth of the glass is dissolved by the acid of the fluor, carried over with it in the gaseous state, and in part deposited in the receiver containing water; Scheele inferred that siliceous earth was here formed by the union of fluor acid and water; and, persisting in his error, he endeavours to show that the same formation ensues in metallic vessels, and therefore independent of glass; but he takes no due precautions against the presence of silica in the fluor he used. Yet there is much to praise in the methods of analysis employed in investigating the nature of this singular body; it is a subject full of difficulties, and can scarcely be called complete even at the present day, though it has engaged the attention of the most acute analysts. The acids of arsenic and of molybdenum were first examined by Scheele, and he first shewed the difference between Molybdenum and Plumbago, and pointed out the existence of charcoal and iron in the latter.

In 1778 Scheele made known the preparation of Arsenite of Copper, and recommended it as an useful and permanent colour in oil and water painting; and in 1779 he took up the important subject of the decomposition of neutral salts by unslaked lime and iron. He found upon the iron hoops of a tub of salted turnips, which had been placed in a damp cellar, a quantity of salt resembling mineral alkali, and was struck with the circumstance, "knowing that the attraction of acid of salt is weaker for iron than for mineral alkali." He dipped plates of several other metals into solutions of common and Glauber's salt, but found that iron only was effectual in their decomposition, and that the action was more rapid in a damp cellar than elsewhere; he also found that quicklime decomposed those salts in the same situation; and that the decomposition was dependant upon the presence of carbonic acid in the atmosphere of the vault.

In the essays on Milk and Sugar-of-milk, there are many curious circumstances respecting the action of re-agents upon that liquid, and these papers deserve particular notice, as among the earliest specimens of the analysis of animal fluids. Chemists are at present undetermined respecting the nature of the acid generated in sour milk; it is most probably vinegar, modified by the presence of animal matter; some consider it as a distinct compound, and have called it *Lactic Acid.* SCHEELE observes that, from his experiments, it appears "that the acid of milk is an acid of a peculiar kind, and though it expels the vinegar from acetated vegetable alkali, yet it seems destined, if I may so speak, to be vinegar." He attributes its difference to the want of some ferment, and shows that the addition of a little brandy to milk, causes it, when fermented, to afford good vinegar.

The method of obtaining the Citric and some other vegetable acids, by decomposing their compounds with lime by sulphuric acid, is also among SCHEELE's discoveries; and his essays on Tungsten, on the preparation of Calomel in the humid way, on Urinary Calculi, on Ether, and on Benzoic acid, each contain important facts, and display new modes of inquiry: they deserve the perusal of those who may be engaged in investigations relating to the several subjects of which they treat.

The last essay to which I shall advert in this historical view of SCHEELE's discoveries, was published in 1782, and is entitled *Experiments on the Colouring Matter of Prussian Blue.* This very singular substance was accidentally discovered early in the last century, by DIESBACH, a colour-maker at Berlin: the preparation was, however, kept secret till published by WOODWARD, in 1724. In 1752 MACQUER's dissertation upon it presented a connected view of its chemical history, which, however, was imperfect and unsatisfactory. SCHEELE directed his attention to the discovery of the principle upon which its colour depended. He shows that the salt afforded by digesting Prussian blue in caustic potash is a triple compound of the colouring principle, iron, and potash iron being the medium by which the colouring matter is attached to the alkali: this salt he decomposed by distilling its aqueous solution with a small quantity of concentrated vitriolic acid, and the liquor which passed into the receiver carried with it a great portion of the colouring principle, which has since been termed *Prussic Acid*. SCHEELE then goes on to show that the action of this acid, in its pure state, upon metallic solutions, is very different from that which it exhibits when combined with alkalis. United with lime, he found that it afforded precipitates in the greater number of metallic solutions. Our author enters into much interesting speculation and experiment, relating to the nature of this colouring principle; and considering the difficulty of the subject, treats it with perspicuity and success. It is only very recently that this inquiry has been perfected by M. GAY-LUSSAC, whose essay relating to it is among the most perfect models of chemical investigation.

SCHEELE's dissertation on Prussian blue was nearly his last contribution to the science which he had so much embellished and improved, for he died in 1786, at the age of forty-four.

It requires no deep inquiry, or minute investigation, to detect, in the researches of PRIESTLEY, SCHEELE, and CAVENDISH, the materials of which their contemporary LAVOISIER, aided by several celebrated chemists of the French school, constructed his new theory; and a retrospect of the works of MAYOW and HOOKE will show that the Antiphlogistic System almost necessarily arose out of a combination of their views with the more modern discoveries. In maintaining, however, that the materials employed in raising this celebrated system were of foreign, and chiefly of British origin, I would by no means be understood as detracting from the indisputable merit of those to whose persevering diligence chemistry owes so much of its present importance; by whom the scattered and unconnected facts of the science were brought together and arranged; and who cleared its paths of the numerous obstructions with which they were previously beset.

§ XII.

The numerous and important contributions with which the celebrated but unfortunate Lavoisier* enriched the chemistry of his time are to be found in the *Memoirs of the Royal Academy of Sciences of Paris;* but as he has chiefly been celebrated as a theorist, I shall here confine myself to such of his inquiries as bear upon that celebrated reform in the science, by which a new nomenclature was introduced, and which ended in the banishment of phlogiston. In this reform Lavoisier took the lead, and though his original investigations connected with it are few and comparatively unimportant, he availed himself with so much skill and success of the labours of others, as, by placing them in new points of view, and exhibiting their unexpected applications, to render them almost his own. Lavoisier's character has, in some measure, suffered by the misguided zeal of his admiring commentators, who, not satisfied with allowing him his due merit for the logical precision and sagacity of induction which he brought into chemistry, have represented him as having the experimental activity of Priestley, and the laborious diligence of Scheele. But Lavoisier, though a great architect in the

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* Born in 1743, at Paris, where he fell a victim to the Revolution, on the 8th of May, 1794.

science, laboured little in the quarry; his materials were chiefly shaped to his hand, and his skill was displayed in their arrangement and combination.

A connected view of his principal reasonings and most prominent researches will be found in his *Elemens de Chimie*, published at Paris, in 1789. This work, in every way eminently important, is divided into three principal sections: the first treats of the formation and decomposition of aëriform fluids, of the combustion of simple bodies, and the formation of acids: the second, of the combination of acids with salifiable bases, and of the formation of neutral salts; and the third, of the instruments and operations of chemistry.

The first section opens with a discussion concerning the Nature and Operations of Heat, which he defines as a real and material substance, or a very subtile fluid, separating the particles of bodies from each other, by insinuating itself among them. This exquisitely attenuated substance he calls *Caloric*, and though he allows that light, in many instances, produces phenomena analogous to those of heat, though they have certain qualities in common, their identity not having been demonstrated they are to be considered as distinct: he then dwells upon the requisite caution in investigating the properties of caloric, since they are known only by fleeting and difficultly ascertainable effects; "it is in those things," he says, "which we neither see nor feel, that it is especially necessary to guard against the extravagancies of the imagination, which always inclining to overstep the bounds of truth, is difficultly restrained by the narrow limits of facts." The influence of heat upon the states of bodies is then illustrated, and their relative capacities for heat alluded to. He says that solidity, liquidity, and aëriform elasticity, are only three different states of existence of the same matter, or three particular modifications which almost all substances are susceptible of assuming successively, and which solely depend upon the degree of temperature to which they are exposed, or, in other words, "upon the quantity of caloric with which they are penetrated." In consequence of this influence of caloric, the possible existence of certain metallic substances in our atmosphere is inferred; "such a substance, for instance, a little more volatile than mercury, might exist there." Lavoisier then proceeds to the analysis of atmospheric air, which he effects by exposing fifty cubical inches of it to heated mercury; it undergoes a decrease equal to one-sixth of its original bulk, and becomes unfit for respiration and combustion; at the same time, the quicksilver is partly converted into a reddish matter, 45 grains of which heated red-hot in a proper retort, afforded 41.5 of running mercury, and 7 or 8 cubical inches of gas, eminently supporting combustion, and being the dephlogisticated air discovered by Priestley. The re-combination of the 42 cubical inches of the mephitic air of the retort, with the 8 cubical inches of dephlogisticated air, separated from the mercury, re-produce 50 cubic inches of atmospheric air.

Lavoisier considered all aëriform fluids as compounds of a ponderable basis, with caloric and light: in the above experiment, the ponderable part of the dephlogisticated air unites to the quicksilver, but the union is effected so slowly, that the phenomena of combustion are not perceived; if, however, red-hot iron wire be introduced into the air evolved from the red compound of quicksilver, it acts rapidly upon it, and its decomposition is attended by the copious evolution of heat and light, while the iron undergoes an increase in weight equivalent to that of the air absorbed.

In discussing the principles of nomenclature, most applicable to the different aëriform fluids, Lavoisier retains, after the example of Macquer, the word *gas*, used first by Van Helmont, as a generic term for all that differ from atmospheric air: he shows that one of the most general properties of vital or dephlogisticated air is to form acids, and hence he gives it the name of *oxygen gas*; the other element of the atmosphere is called *azotic gas*, from its fatal effects upon animal life, a term, "commendable," says LAVOISIER, "because it only expresses a matter of fact."

The combustion of sulphur, phosphorus, and carbon, is next shown to be attended with the same phenomena as that of iron, namely, the extrication of heat and light, with the union of the ponderable part of the oxygen with the combustible; and the principles of nomenclature applicable to these different compounds are developed. Where oxygen does not form an acid, its compounds are termed *oxides;* and where more than one oxide, or acid, is formed, the termination of the base indicates its nature: thus there are four compounds of nitrogen with oxygen, two oxides, and two acids; the former are respectively termed *nitrous* and *nitric oxides;* and the latter, *nitrous* and *nitric acids;* the *minimum* and *maximum* of oxygen being in each case designated by the termination *ous* and *ic.* The term *hydrogen* is applied to inflammable air, shown by CAVENDISH to be the basis of water; and fixed air is called *carbonic acid,* since it is identical with the result of the combustion of charcoal in oxygen. In connexion with the latter subject, LAVOISIER made the grand discovery of the production of carbonic acid by the combustion of the diamond. The destruction of this gem by fire was demonstrated by the Florentine Academicians as early as 1690; they exposed a diamond to the focus of a burning lens, and found that it was entirely evaporated; and Francis the First, of Germany, witnessed the same phenomenon in the heat of a furnace. LAVOISIER proved that the diamond underwent no change when air was excluded; and that, when ignited in oxygen gas, it produced carbonic acid: whence the inevitable conclusion that the diamond and charcoal are identical in their nature; and that the vast difference in their appearance and mechanical qualities is the result of aggregation; that the one is crystallized, the other in a less indurated form. Unprecedented as such an idea may seem, it is not only warranted by the experiments of LAVOISIER and others, but also in some degree supported by analogy. Thus, when argillaceous earth, which is a white pulverulent substance, is aggregated by mechanical attraction into a crystalline form, it constitutes the sapphire, one of the hardest and least destructible of the gems. In one state, the earth is soft, and readily soluble in acids; in the other, its insolubility equals its induration: but there is one invincible anomaly relating to the conducting power of the diamond and charcoal in regard to electricity; the former ranks among the non-conductors, the latter is a conductor; and hitherto mechanical texture has not been shown, in any analogous cases, to interfere with the power of conducting electricity.

Among those who have further explored the phenomena of the combustion of the diamond, and who have verified and extended the original views of LAVOISIER, we find the names of the most eminent European Philosophers. Few subjects in Chemistry have been so eagerly pursued, and the united results of different experimentalists have rarely tallied with the precision which these researches present *.

LAVOISIER was the first who examined with requisite accuracy the products of the distillation of vegetable and animal substances, and who drew a line of distinction between the educts and products thus afforded; he also inquired, with

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* That the quantity of carbonic acid, afforded by a given weight of diamond, is the same as that yielded by a similar quantity of charcoal, is the great proof of the identity of those apparently dissimilar substances: this was demonstrated in the year 1796, by the refined and elegant experiments of Mr. Tennant, whose untimely loss society has lately had to deplore. Mr. Tennant was a profound philosopher, and a matchless companion:—his learning was without pedantry; his wit without sarcasm;—he was deep, but always clear; gentle, but never dull. To those who knew him not, it is scarcely possible to offer an adequate representation of his singularly pleasing and enlightened character;—by those who enjoyed his acquaintance, and partook of his social hours, his extent of knowledge, his happy and unrivalled talent for conversation, his harmless but brilliant flashes of merriment, and all his amiable peculiarities, can never be forgotten.

Mr. Tennant was born in Yorkshire in 1761, and died at Boulogne in 1815.

See *Biographical Account* of Smithson Tennant, Esq., in Thomson's *Annals of Philosophy*, vol. vi.

more success than any of his predecessors, into the phenomena of fermentation, and by examining the contents of certain vegetable juices previous to and after that process, he drew some very curious conclusions respecting the changes that take place.

In his observations upon salifiable bases, and the formation of neutral salts, Lavoisier has described the phenomena of the solution of metals in the various acids: he adverts to the oxidizement of the metals previous to their solution, and to the consequent liberation of hydrogen; and has the following acute surmise respecting the nature of the alkaline earths, which then were considered as elementary bodies. "From these phenomena it appears that oxygen is the bond of union between metals and acids, and from this we are led to suppose that oxygen is contained in all substances which have a strong affinity with acids; hence it is very probable that the four eminently salifiable earths contain oxygen, and that their capability of uniting with acids is produced by the intermediation of that element. What I have formerly noticed relative to these earths, namely, that they may very possibly be metallic oxides, with which oxygen has a stronger affinity than with carbon, and consequently are not reducible by any known means, is considerably strengthened by the above considerations." Sir H. Davy, in showing the combustibility of the metals of the alkalis in carbonic acid, has verified this anticipation.

In the second part of the *Elements*, Lavoisier treats of the formation of Neutral Salts, and throws out new and important views relating to the constitution of chemical compounds. Speaking of the influence of Light as a chemical agent, he adverts to its singular action upon the vegetable kingdom, and supposes that it combines with certain parts of vegetables, and that the green of their leaves, and the various colours of their flowers, are chiefly owing to this combination. "This much," he says, "is certain, that plants which grow in darkness are perfectly white, languid, and unhealthy, and that to make them acquire vigour, and recover their natural colours, the direct influence of light is absolutely necessary. Somewhat similar takes place even in animals. Mankind degenerate to a certain degree, when employed in sedentary manufactures, or living in crowded houses, or in the narrow lanes of large cities; whereas they improve in their nature and constitution in most of the country labours which are carried on in the open air."

In these observations there is much irrelevant matter. The chemical action of light is a subject which scarcely seems to have attracted due attention. The remarks of Lavoisier incorrectly refer its influence to direct combination; it rather appears to modify, and generally to exalt, the mutual agencies of bodies, of which we have some remarkable instances in the action of chlorine upon hydrogen, and upon carbonic oxide; and of chlorine and several of the chlorides upon water, from which it occasions the evolution of oxygen and the production of muriatic acid, a change which gave rise to the idea of the existence of oxygen and muriatic acid as the components of chlorine, the agency of the water and the nature of the muriatic acid not having been taken into the account.

In his observations on the combinations of oxygen, the conditions requisite to the oxidizement of bodies are mentioned; such as the diminution of aggregation by heat, which causes many substances to attract the oxygen of the atmosphere; their ignition with nitre, or with chlorate of potassa; and their solution in certain acids, especially the nitric. The combinations of the different combustible substances are next reviewed, and those of the acids and of some other compound bodies.

The third part of the *Elements* is occupied with the description of a variety of chemical operations, which were exceedingly improved and extended by Lavoisier. He shines as the inventor of costly and complicated apparatus, the greater part of which might, however, have been superseded by simpler and cheaper utensils.

This sketch of the contents of LAVOISIER'S *Elements of Chemistry* will sufficiently show the extent and perspicuity of his views as a theorist; and though the arrangement is now open to much objection, it was then admirably calculated for the use of the student, and well fitted to display the strongest parts of the anti-phlogistic system in the most favourable light: it was, indeed, impossible, that any one of unbiassed judgment could seriously retain the phlogistic doctrines after the perusal of this masterly refutation; but if we look to the abstract facts upon which it rests, we shall search in vain, either in the works of LAVOISIER, or in those of his contemporaries: they were exclusively furnished from other quarters; and, without any undue prejudice, of which, indeed, science should always stand divested, they will, I think, chiefly be found in the writings of MAYOW and HOOKE, and in those of PRIESTLEY and SCHEELE. The prominent features of the French theory are its explanation of the phenomena of combustion and of acidification, the presence of oxygen being deemed essential in both cases. That air is the food of fire was known in the remotest ages; that it causes the increase of weight sustained by metals during their fusion and calcination, was shown by REY early in the seventeenth century; that a part, only, of the atmosphere, is concerned in the support of flame, was explained by HOOKE in 1667; and that the vital or igneous spirit, as he terms it, of the atmosphere, is concerned in the formation of acids, was asserted by MAYOW in 1674. Here, without advancing into the eighteenth century, we have, in explicit detail, all the facts and arguments requisite for the construction of the French theory; but if to these we add the discovery of Oxygen by PRIESTLEY, and of the composition of water by CAVENDISH, what then becomes of its claim to originality?

It must be regretted, that those who have censured LAVOISIER with the uncandid and unacknowledged appropriation of the thoughts of others, have some grounds for the accusation.

In bringing forward his theory of combustion, why did he smother the lucid opinions of Rey and Mayow? why refuse praise and acknowledgment to Black and Scheele and Cavendish? or why appropriate the discovery of oxygen, in the face of the prior, indisputable, and known claims, of his friend and contemporary Priestley? These are questions we cannot now answer; but those who have grounded harsh, indiscriminate, and severe censure upon such accusations, have neither been animated by the independent spirit of true philosophy, nor guided by the unbiassed love of truth. It must be remembered, that Lavoisier was never fairly confronted by these rivals and antagonists; that unintentional inadvertency often accompanies scientific ardour; that, in the eagerness of pursuit, he may have neglected that which, in a calmer hour, he would have seen, regretted, and acknowledged; and that, in the hurry of discussion and heat of controversy, he was suddenly summoned to eternity[*].

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[*] Two scarce volumes of the posthumous works of Lavoisier are extant, consisting, in great measure, of extracts from, and sketches of his different papers read before the Royal Academy of Sciences, but several original Observations and Essays are also dispersed among them. They, in some degree, justify the observation which I have made in the text, that, had Lavoisier lived, he would have done merited justice to his predecessors and contemporaries, for he candidly reviews their opinions and compares them with his own; at the same time, the following passage cannot be regarded as perfectly candid towards Rey, who, as I have shown above, founded his arguments not upon hypothesis, but upon experiment.

I insert a long quotation, that there may be no misunderstanding upon the subject.

After stating the prevailing phlogistic notions entertained at that period, he proceeds as follows:—"Tel étoit l'etat des connoissances, lorsqu'une suite d'expériences, entreprises en 1772 sur les différentes espèces d'air, ou de gaz qui se dégagent dans les effervescences et dans un grand nombre d'opérations chimiques, me firent connoître, d'une manière démonstrative, quelle étoit la cause de l'augmentation de poids, qu'acquiérent les metaux lorsqu'on les expose à l'action du feu. J'ignorois alors ce que Jean Rey avoit écrit à ce sujet en 1630; et quand je l'aurois connu, je n'aurois pu regarder son opinion à cet égard, que comme une assertion vague, propre à faire honneur au gènie de l'auteur, mais qui ne dispensait pas les chemistes de constater le verité de son opinion par des expériences. J'étois jeune, j'étois nouvellement entré dans la carrière des sciences, j'étois avide gloire, et je crus devoir prendre quelques précautions pour m'assurer la propriété de ma découverte. Il y avoit à cette époque, une correspondance habituelle entre

Although Lavoisier made few original discoveries, his talents were, perhaps, more usefully employed in setting forth and elucidating the researches of others, a task which he performed with great skill and success : in reviewing hypotheses, he diligently contrasts them with facts ; weight and measure, which had been introduced into chemistry by Bergman, were

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les savans de France et ceux d'Angleterre ; il regnoit entre les deux nations, une sorte de rivalité qui donnoit de l'importance aux expériences nouvelles, et qui portoit quelquefois les écrivains de l'une ou de l'autre nation, à les contester à leur véritable auteur ; je crus donc devoir déposer, le 1er Novembre 1772, l'écrit suivant cacehté, entre les mains du Secrétaire de l'Académie. Ce dépôt a été ouvert à la séance du 5me Mai suivant, et mention du tout a été faite en tête de l'écrit. Il étoit conçu en ces termes :—

" Il y'a environ huit jours que j'ai découvert, que le soufre en brûlant, loin de perdre de son poids, en acquiéroit au contraire ; c'est à dire, que d'une livre de soufre on pouvoit retirer beaucoup plus d'une livre d'acide vitriolique, abstraction faite de l'humidité de l'air ; il en est du même du phosphore : cette augmentation de poids vient d'une quantité prodigieuse d'air qui se fixe pendant la combustion, et qui se combine avec les vapeurs.

" Cette découverte que j'ai constatée par des expériences que je regarde comme décisives, m'a fait penser que ce qui s'observoit dans le combustion du soufre et du phosphore, pouvoit bien avoir lieu à l'égard de tous les corps qui acquiérent du poids par la combustion et la calcination : et je me suis persuadé, que l'augmentation de poids des *chaux* métalliques, tenoit à la même cause. L'experience a complettement confirmé mes conjectures : j'ai fait la reduction de la litharge dans des vaisseaux fermés, avec l'appareil de Hales, et j'ai observé qu'il se dégagéoit, au moment du passage de la *chaux* en métal, une quantité considérable d'air, et que cet air formoit un volume au moins mille fois plus grand que la quantité de litharge employée. Cette découverte me paroissant une des plus intéressantes qui ait été faite depuis Stahl, j'ai cru devoir m'en assurer la propriété, en faisant le present dépôt entre les mains du Secrétaire de l'Académie, pour demeurer secret jusqu'au moment où je publierai mes experiences."

(Signé) " Lavoisier."

" En rapprochant cette première notice de celle que j'avois déposée à l'Académie le 20me Octobre précédent, sur la combustion du phosphore, du mémoire que j'ai lu à l'Académie à sa séance publique de Pâques 1773, enfin, de ceux que j'ai successivement publiés, il est aisé de voir, que j'avois conçu dés 1772, tout l'ensemble du systême que j'ai publié depuis sur la combustion. Cette théorie à laquelle j'ai donné de nombreux dévelloppemens en 1777, et que j'ai porté, presque dés cette époque à l'état où elle est aujourdhui, n'a commencé à être ensignée par Fourcroy, que dans l'hyver de 1786 à 1787 ; elle n'a été adoptée par Guyton Morveau, qu'à une époque postérieure ; enfin, en 1785 Berthollet écrivoit encore dans le systême du phlogistique. *Cette theorie n'est donc pas, comme je l'entends dire, la théorie des Chimistes François : elle est la mienne* et c'est une propriété que je réclame auprés de mes contemporains et de la postérité."

strictly insisted upon in all his manipulations, and in his hands chemistry assumed the features of a new branch of knowledge, and put on that character which, at no very distant period, must probably render it a general study.

Connected with the labours of LAVOISIER is the celebrated reform of chemical nomenclature effected by him and his associates, among the most eminent of whom we may enumerate GUYTON MORVEAU *, and FOURCROY †, two men who may be considered as ornaments of their age and country. The former amidst varied occupations pursued chemistry with successful diligence, and, had he given nothing else to the science, his name deserves to be transmitted to posterity, as the inventor of the means of destroying infection by acid vapours, the efficacy of which he first pointed out in the year 1773. His first essay on the reform of nomenclature was published in the *Journal de Physique* for May 1782, and although it was strenuously opposed by the colossal power of the Royal Academy of Paris, the plan was not only afterwards approved, but prosecuted by the eminent Chemists of that metropolis. The different papers and correspondence relating to this subject are, in many respects, curious and interesting from the difference of opinion which prevailed respecting the terms he adopted, and the ultimate benefit likely to result from the reformation. FOURCROY is a well known name in the chemical world; his works rank among the most celebrated which France has produced in the science, though they are sometimes deficient in candour, and correctness. He is the first author who published a system of chemistry.

The difficulties attending an entire reform in the nomenclature of chemical science may be well imagined, and they were encountered with considerable address; and it must be confessed, that, while it particularly tended to the dissemination of the anti-phlogistic doctrines, it facilitated the general

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* Born at Dijon, 1737; died, 1815.

† Born at Paris, 1755; died, 1809.

acquisition of the science; the ludicrous terms of the alchemists were rejected, and names founded upon the nature of compound bodies, and upon the leading qualities of elementary substances, became their more sensible substitutes.

Had chemistry remained stationary, or nearly so, the French nomenclature, if not unobjectionable, would, at least, have been efficient: but, independent of those imperfections evinced by a reference to the philosophical principles of language, the plan was quite unsuitable to a branch of knowledge so eminently and rapidly progressive. Hence, many of the terms, once unexceptionable, are now become, not merely objectionable, but absurd, and are only retained in consequence of the very serious inconvenience to which innovation necessarily tends. I have consequently, in the following pages, checked myself whenever I felt inclined to change old and accepted terms for those of more recent coinage; and, in the selection of names necessarily new, I have preferred such as are most analogous to those previously in use, being convinced that a partial reform would be useless; and a radical one, mischievous. For these reasons, I have declined the adoption of Sir HUMPHRY DAVY's principles of nomenclature, to whose subjoined opinion, however, upon this subject, I entirely subscribe *.

"Simplicity and precision ought to be the characteristics of a scientific nomenclature; words should signify things, or the analogies of things, and not opinions. If all the elements were certainly known, the principle adopted by LAVOISIER would have possessed an admirable application; but a substance in one age supposed to be simple, in another is proved to be compound; and *vice versâ*. A theoretical nomenclature is liable to continued alterations; *oxygenated muriatic acid* is as improper a name as *dephlogisticated marine acid*. Every school believes itself in the right; and if every school assumes

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* Elements of Chemical Philosophy, pp. 46, 47.

to itself the liberty of altering the names of chemical substances, in consequence of new ideas of their composition or decomposition, there can be no permanency in the language of the science; it must always be confused and uncertain. Bodies which are similar to each other should always be classed together; and there is a presumption that their composition is analogous. Metals, earths, alkalies, are appropriate names for the bodies they represent, and independent of all speculative views; whereas, oxides, sulphurets, and muriates, are terms founded upon opinions of the composition of bodies, some of which have been already found erroneous. The least dangerous mode of giving a systematic form to a language seems to be, to signify the analogies of substances by some common sign affixed to the beginning, or the termination of the word. Thus, as the metals have been distinguished by a termination in *um*, as *aurum*, so their calciform, or oxidated state, might have been denoted by a termination in *a*, as *aura;* and no progress, however great, in the science, could render it necessary that such a mode of appellation should be changed. Moreover, the principle of a composite nomenclature must always be very limited. It is scarcely possible to represent bodies consisting of five or six elements in this way, and yet it is in such difficult cases that a name implying a chemical truth would be most useful."

Among the causes that have contributed to the recent progress of chemical science, we have already had occasion to advert to the doctrine of definite proportionals, which has enabled us to submit many of the phenomena of chemistry to calculation, and which promises to elucidate some of its most abstruse parts upon mathematical principles; but the chief source of the rapid advancement of chemistry during the present age, is doubtless the discovery of the relation of electrical to chemical changes; a discovery which has unfolded entirely new views of the mutual agencies of bodies, and which has equally furnished the theoretical and practical chemist with materials for speculative and experimental inquiry.

That the contact of different metals is frequently attended by their electrical excitation seems first to have been observed by Mr. Bennet in the year 1789 *; and the curious experiments of Galvani upon the convulsions excited in the limbs of animals, by the application of certain metals to their muscular and nervous fibres, led Volta to investigate the cause of such phenomena, and to attempt the accumulation of such electricity, which he attained by a succession of copper and zinc plates with intervening pieces of moistened pasteboard: one extremity of this pile was always in the positive, and the other in the negative, electrical state, and the quantity and intensity of the electricity were found to augment with the number of alternations.

This instrument has been productive of two series of discoveries in chemistry, one of which has arisen out of its power of producing heat, and the other from its peculiar influence over the composition of bodies. The former has taught us the fusion and combustion of a number of substances; the latter has developed a new cause which influences chemical effects, depending upon the communication of attractive and repulsive energies to the elements of compound bodies.

Substances, held together by the strongest known affinities, suffer decomposition when submitted to the action of this all-powerful agent, and one series or class of elements is always attracted by the one pole, and another by the oppositely electrical surface; and it has been inferred from these facts, that one power is productive of electrical and of chemical changes, acting in the former instance upon masses of matter; in the latter, upon its elementary particles.

Such are the general conclusions deducible from the researches and discoveries of Sir H. Davy in this comparatively new and curious department of chemical philosophy, into the

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* Philos. Trans.

history of which I shall enter a little more in detail, chiefly with a view of showing the singular talent and sagacity with which a difficult and intricate branch of science was successfully pursued and illustrated by that eminent individual.

It appears from the "*additional observations*" appended to his *Chemical Researches*, upon nitrous oxide, &c. published in 1800, that Sir H. DAVY had no sooner heard of VOLTA's researches, than his mind was awakened to their bearings upon chemical changes, and from that period to the time of his first publication upon the subject, he seems not to have lost sight of the inquiry; indeed, it was his characteristic habit to examine without delay all novel results of other philosophers, and when he had confirmed their accuracy, he generally rendered them subservient to further discovery. Accordingly we find that the first paper which he presented to the Royal Society (read the 18th of June, 1801), was "*An Account of some Galvanic Combinations formed by the arrangement of single Metallic Plates and Fluids, analogous to the Galvanic Apparatus of Volta*," and it contains several curious and interesting facts upon a subject which now began to excite general attention, and attracted the notice of many skilful experimentalists. Still, however, the great harvest of fame in this field of inquiry was reserved for Sir H. DAVY, and the Bakerian Lecture for 1806 contains a series of propositions and experiments, in reference to the chemical agencies of electricity, which at once display the masterly energies of the author's mind in passing from experiment to theory, and in the employment of that theory as the source of new, profound, and elaborate researches. About the time this paper was published, a great and important question respecting the agencies of voltaic electricity was undecided; it was not known whether electricity had the power of *generating* certain forms of matter, or whether they were merely *elicited* by its influence, from compounds, which escaped common modes of detection. Water, for instance, was found not merely to be resolved into its ultimate gaseous components, but their evolution was constantly connected with the appearance of acid and alkaline matter, and *that*, although every precaution was apparently taken to exclude foreign matters and all sources of impurity. Hence it was imagined that water contained the elements of these bodies, or that it produced them by uniting with the electric fluids, or that they were actually conveyed by some mysterious route from the cells of the pile: indeed it would be useless to enumerate all the speculations originating in these paradoxical phenomena; but it will be profitable to glance at the manner in which the difficulties were encountered by our author. He first repeated all that had been done by others, and criticised and compared their proceedings; he then electrized distilled water, and found, as they had found, the evolution of saline, alkaline, and acid bodies; but he also found that the more rigidly he purified the water, the smaller was the evolution of saline products; a fact militating against their supposed source: still, however, they made their appearance. He now directed his attention to the vessels which were used, and succeeded in referring to them several extraneous bodies; thus glass, porcelain, and several mineral substances, yielded more or less foreign matter, which was successfully excluded when gold or platinum were substituted; but still, water, which had been re-distilled at a low temperature in a silver alembic, did afford acid and alkali; the source of this was next traced to the hands of the operator, and the accidental contact of test papers, all which were consequently avoided, with a proportionate diminution of the problematical appearances; but they were yet present, for notwithstanding all the precautions which I have enumerated, litmus was reddened in the positive, and turmeric rendered brown in the negative vessel: it was now, however, found that the acid and alkali were nitric acid and ammonia, substances producible by new arrangements of the elements of air and water, and accordingly when very pure water, carefully deprived, and kept from the contact, of air, was electrized in vacuo, in cones of gold, which had not been handled, nothing but oxygen and hydrogen were elicited from it.

The question, therefore, concerning the origin of the appearances cited was now so far satisfactorily determined. The paper enters into many valuable contingent inquiries, and proves this essential fact, that electricity has the power not merely of rendering evident the smallest traces of foreign matter, but of decomposing compounds with apparent facility and perfection, the elements of which are held together by the strongest chemical attractive force; whence it was concluded that substances hitherto deemed simple or elementary might, under this all-powerful decomposing agent, afford evidence of a compound nature, and yield either known or new elementary bodies. The inquiry was accordingly resumed under this new light; and the Bakerian Lecture, read to the Royal Society in November 1807, contains the results to which it led. The first substances which occurred as likely to afford successful and novel information were the fixed alkalis. Upon subjecting caustic potassa to the action of the voltaic pile, it was found not to conduct electricity, and when its aqueous solution was used, the water only appeared to suffer decomposition. After several unsuccessful trials, it was at length found that the alkali, gently breathed upon, became sufficiently moist to suffer the transfer of electricity, and the appearances were very remarkable; effervescence ensued at the positive pole, and at the negative there appeared small and brilliant globules of a perfectly metallic appearance, but which presently burned upon exposure to air, and seemed to reproduce the alkali. There now could be little doubt that this matter was the base of potassa, but it became necessary to collect and preserve it for examination, and this was a task attended by many serious and apparently insurmountable obstacles, for the globules were successively immersed in a great variety of fluids, upon all of which they had more or less action, and none of which afforded a means of retaining them in a metallic state; at length the fluid called *naphtha* was successfully employed, and in it they were collected and preserved for a considerable time without material alteration. They were found truly metallic, eminently combustible, remarkably light, acting energetically and inflaming upon water, and producing potassa by their union with oxygen. Many of their other properties were also determined; and it here deserves especially to be mentioned, that although *potassium*, for so this new metal was called, was only obtained in minute atoms and a few grains in weight, all its essential properties, as subsequently determined, were correctly and minutely made out. *Sodium* was next obtained from soda by the same new method of decomposition; and shortly after the alkaline earths were shown to contain analogous highly inflammable and metallic bases. The Philosophical Transactions for several subsequent years contain continuations of these inquiries, which were actively and successfully pursued by their author, and which speedily attracting the admiration of the scientific world, induced others to resume and extend them.

In the year 1810, the subject of Sir HUMPHRY'S Bakerian Lecture is the "Oxymuriatic acid and its compounds," a subject which is pursued in several successive communications, abounding in original views and new discoveries. It is in these papers that the true nature of oxymuriatic acid is demonstrated, that the views of SCHEELE respecting it are established, and that the erroneous reasoning regarding its composition, originating with the French and sanctioned by the assent of the chemists of Europe, is refuted and subverted. Much acute reasoning and many admirable specimens of the true logic of the science are to be found in these details, blended with sound descriptions of new compounds, and new applications of the facts that were developed: it is here that the nature of the muriatic acid is first demonstrated, that oxymuriatic acid (under the new name of *chlorine*) is shown to be an undecompounded substance, that a multiplicity of erroneous views respecting their compounds are corrected, and others established upon the basis of experiment, to the exclusion of all hypothetical reasoning. The new theory to which these inquiries necessarily led was actively canvassed and opposed; but the objections urged against it soon yielded to the sound arguments and unequivocal experiments upon which it was founded, and the fame which the author acquired by the gradual admission and general adoption of these new modes of reasoning and of research, was scarcely inferior to that which rewarded his more brilliant discovery of the alkaline bases. The several papers which follow this Lecture, and in which, among other subjects, the nature of fluorine and of iodine are discussed, may be considered as continuations and illustrations of the Bakerian Lecture, and they each contain further proofs of the inventive genius and almost unrivalled talent of generalisation possessed by their author.

Davy had now established himself as the first chemist of Europe; and whether we found his claims to that distinction barely upon the number and importance of his original discoveries, or upon the profundity of his reasoning powers displayed in their applications, and stamping a peculiar character upon his inquiries, it must be allowed that he was eminently entitled to it. About this time he became desirous of embodying the results of his labours, and of displaying them in a more connected and systematic form, and accordingly in 1810 he published the first volume of his *Elements of Chemical Philosophy*, a work which, though it bears some marks of hasty composition, is abundant in evidence of the author's talent as an eloquent writer, a clear reasoner, and a shrewd and sagacious experimentalist. It is to be regretted that the second volume of this work never appeared; for although it be true that the first chiefly embraced those parts of the science which had been the particular objects of his successful studies, it cannot be doubted that his genius would have cast a new light upon those parts of chemistry with which he was less immediately intimate. His *Elements of Agricultural Chemistry* appeared shortly after the *Chemical Philosophy*; it is a work containing some new and useful facts and views, and is well adapted to the capacities of those whom he intended to instruct.

Sir Humphry had now laid a secure and deep foundation of permanent eminence and imperishable reputation as a chemical philosopher of the first class; but whilst he was thus employed, he was at the same time reaping equally verdant, though less durable laurels, as a lecturer; his style was peculiar and impressive, though not elegant; his eloquence florid, but powerful and appropriate; his experiments brilliant and original; and his reasoning refined and wonderfully acute. But, to dwell further upon this subject, would lead me to biographical particulars respecting his connexion with the Royal Institution, and to details not immediately connected with my present object, which I willingly, and, indeed, anxiously avoid, and turn with pleasure to his discovery of the Safety-Lamp.

The first paper in relation to this subject is printed in the *Philosophical Transactions* for 1815, and was followed by four communications bearing upon the same inquiry, the last of which was read to the Royal Society in January, 1817. These essays would alone characterise their author as a philosopher of no common stamp. Finding that flame would not recede through tubes of very small diameters, the idea occurred to him of constructing a lamp, the flame of which should have no connexion with the surrounding air, except by capillary tubes; and he inferred from previous experiments, that such a lamp might safely be employed for the illumination of coal-mines infested with the explosive atmosphere commonly called *fire-damp*. He then endeavoured to ascertain the extent to which the tubes might be shortened without interfering with the principle of safety, and was thus led to cut them down till their transverse section resembled a series of fine meshes: this so closely resembled wire-gauze, that he was induced to try how far that tissue would prevent the passage of flame, and, finding it effectual, he employed it in the construction of his lamp, and ultimately adopted the simple and efficient arrangement now in general and successful use. His researches respecting the nature of flame, and the temperatures at which combustion may, under various circumstances, be carried on, are parts of this general inquiry, and are not less ingenious than original.

In November, 1820, Sir HUMPHRY DAVY became the President of the Royal Society, and his Discourses delivered on various occasions before that Body, will give a fair idea of the general style of his eloquence and power in oratorical composition. He continued to contribute papers as heretofore, and some of them upon subjects of much interest, ably and philosophically discussed: among them the essays on the modes of protecting the copper sheathing of ships deserve especial notice; but I dare not venture a criticism on these his later efforts.

In the course of the year 1827, Sir HUMPHRY's general state of health became much impaired; he passed the greater part of the year 1828 in Italy, and terminated his memorable existence at Geneva, in May, 1829, in the fifty-second year of his age.

The theory of definite proportionals was adopted and illustrated by Sir H. DAVY, and his *Elements* is the first publication in which it was generally applied. This theory received about the same time extensive elucidation at the hands of M. GAY-LUSSAC, but its promulgation in this country is chiefly to be attributed to Dr. WOLLASTON, whose admirable suggestion of a synoptic scale of chemical equivalents was brought before the Royal Society in November, 1813. Many years previous to this he had established the important doctrine of multiple proportions, in a paper "On Super-acid and

Sub-acid Salts," printed in the *Philosophical Transactions* for the year 1808: he now showed the important practical applications of which the theory was susceptible, and by connecting the scale of equivalents with GUNTER's sliding rule, has put into the hands of the chemist an instrument infinite in its uses, and equally essential to the student, the adept, and the manufacturer.

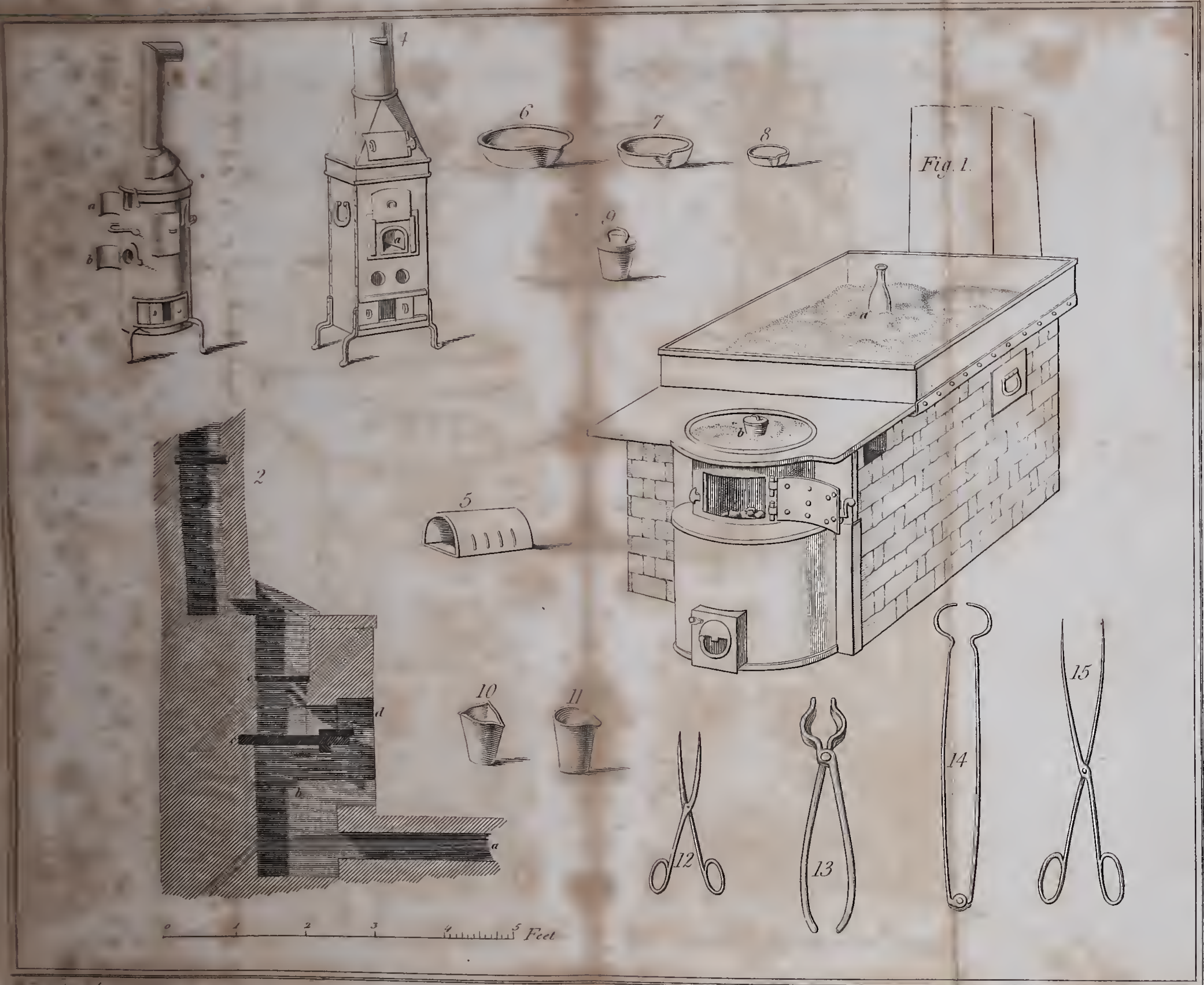
Dr. WOLLASTON's first contribution to the Transactions of the Royal Society was in June, 1797, being an essay *On Gouty and Urinous Concretions*, in which he made known several new compounds connected with the production of those maladies, in addition to the uric combinations previously discovered by SCHEELE: these were, Phosphate of Lime; Ammonia-magnesian Phosphate; a mixture of the two forming the *fusible* Calculus; Oxalate of Lime; and, more lately, he added Cystic Oxide to the list of his previous discoveries. (*Phil. Trans.*, 1810.) In 1804 and 1805, he made known Palladium and Rhodium, two new metals contained in the ore of platinum, and associated with osmium and iridium, discovered about the same time by Mr. TENNANT. In 1809 he showed that the supposed new metal, Tantalum, was identical with Columbium, previously announced by Mr. HATCHETT; and shortly before his death, which happened in December, 1828, in the sixty-third year of his age, he transmitted to the Royal Society the *Bakerian Lecture*, in which he fully describes his ingenious method of rendering platinum malleable.

Dr. WOLLASTON made a few other chemical communications to the Royal Society, but his papers are chiefly on subjects more immediately connected with physical and physiological inquiries: they are all remarkable for the singular and satisfactory simplicity of his experimental methods, for the perspicuity of his theoretical deductions, and for the extreme caution with which he touches upon generalisations and hypotheses. His uncommon tact, neatness, and dexterity as an experimental chemist, will never be forgotten by those who had an opportunity of witnessing his performance of any analytical operation; he practised a peculiar method of microscopic research, in which he willingly instructed those who asked his information; and we owe to him numerous abbreviations of tedious processes, and a variety of improvements in the application of tests, which have gradually become public property, although he never could be induced to describe his manipulations in print, or to communicate to the world his happy and peculiar contrivances.

The loss of two such men as WOLLASTON and DAVY, within the short period of six months, and scarcely beyond the prime of life, must, indeed, be considered as a serious national calamity: the sketch which I have given of their labours is a most imperfect outline; but it would have been improper and indecorous to have dismissed this brief History of Chemistry without such notice; and I earnestly hope that a detailed account of their lives and writings, by those who possess requisite talents and information for the task, will not long be withheld from the public.

A MANUAL OF CHEMISTRY.

Pl. III.



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A
MANUAL OF CHEMISTRY.

CHAPTER I.

OF THE POWERS AND PROPERTIES OF MATTER, AND OF THE GENERAL LAWS OF CHEMICAL CHANGES.

It is the object of Chemistry to investigate all changes in the constitution of matter, whether effected by heat, mixture, or other means. Its general range, therefore, is so extensive, and the individual cases requiring explanation so numerous, that *Arrangement* is of the first consequence to its successful study; and, in the present state of our knowledge, it will be found most convenient to begin with the discussions relating to the general powers or properties of matter, and afterwards to proceed to the examination of individual substances, and to the phenomena which they offer when presented to each other under circumstances favourable to the exertion of their mutual chemical agencies.

The powers and properties of matter, connected with chemical changes, may be considered under the heads of

i. Homogeneous Attraction.
ii. Heterogeneous Attraction, or Affinity.
iii. Heat.
iv. Electricity.

Section I.—Homogeneous Attraction.

Attraction may be regarded as acting at sensible and at insensible distances. In the former case, it is called *gravitation.* It is the power by which substances are propelled towards the earth; it exists in all known forms of matter; and it acts directly as the mass, and inversely as the square of the distance: restrained by *inertia*, it preserves the planetary bodies in their orbits, presides over their movements, and tends to confer upon the system of the universe that consummate harmony which the genius of Newton unveiled.

Attraction is also exerted at insensible distances, and among the minutest atoms of matter. It thus preserves the form, and modifies the texture, of solids; gives a spherical figure to fluids, causes the adhesion of surfaces, and influences the mechanical characters of bodies; and, when it operates upon *dissimilar* particles, it produces their union, giving rise to new and infinitely-varied productions.

The results of attraction, as relating to the texture and forms of matter, are influenced by the circumstances under which it has taken place. Sometimes the particles are, as it were, indiscriminately collected; at others, they are beautifully arranged, producing regular and determinate figures: in this case, bodies of the same composition often affect the same form; hence we are not unfrequently enabled to infer the composition of a substance from accurate inspection of its external or mechanical characters.

Identity of form, however, is not necessarily associated with identity of composition, for certain substances may be substituted for each other in combination, without affecting the form of the compound. Thus the arseniate and binarseniate of soda have the same forms as the phosphate and biphosphate of soda; and the arseniate and binarseniate of ammonia resemble the phosphate and biphosphate of that alkali. Professor Mitscherlich*, to whom we owe these and other facts connected with the subject, terms such salts *isomorphous*, and has shown

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* Ann. de Chimie et Phys., tom. xiv. xix. xxiv.

that there is a remarkable analogy in the chemical arrangement of their constituents. Thus, in the above instances, the proportional quantities of acid, of base, and of water of crystallization, correspond; he has endeavoured to trace a similar correspondence in the atomic constitution of the acids of the salts, but here the resemblance seems sometimes to fail; at least chemists are by no means agreed as to the identity in atomic constitution of the arsenic and phosphoric acids.

The regular polyhedral solids thus resulting from the influence of attraction upon certain kinds of matter are usually called *crystals;* and the bodies are said to be susceptible of *crystallization.*

To enable the particles of bodies to assume that regular form which crystals exhibit, it is obvious that they must have freedom of motion; and, accordingly, the first step towards obtaining a body in its crystalline form, is generally to confer upon it either the liquid or aëriform state. The former is usually effected by solution in water; the latter by exposure to heat.

When common salt is dissolved in water, its particles may be regarded as disposed at regular distances throughout the fluid; and if the quantity of water be considerable, the particles will be too far asunder to exert reciprocal attraction: in other words, they will be more powerfully attracted by the water than by each other. If we now slowly get rid of a portion of the water by evaporation, some of the saline particles will gradually approach each other, and they will aggregate according to certain laws, producing a regular solid of a cubic form; another portion of the salt will remain dissolved in the residuary water, which is usually called the *mother liquor* or water.

The regularity of the figure will be influenced by the rapidity of the evaporation; if the process be slowly conducted, the particles unite with great regularity; if hurried, the crystals are irregular and confused. In common cases, the evaporation may be continued till a *pellicle* forms upon the surface of the solution, which indicates that the attraction of the saline particles for each other is becoming superior to their attraction for the water. The formation, therefore, of a superficial pellicle is the common criterion of the fitness of a solution for crystallization; but where the object is to obtain very regular and very large crystals, the evaporation must be much slower, and carried to much less extent; even *spontaneous evaporation*, or that which takes place at common temperatures, must be resorted to.

There are certain bodies which may be dissolved or liquefied by heat, and, during slow cooling, may be made to crystallize. This is the case with many of the metals, and with sulphur. Some other substances, when heated, readily assume the state of vapour, and, during condensation, present regular crystalline forms; such as iodine, benzoic acid, camphor, &c.: and in this way crystals of snow are produced by the cooling of aqueous vapour.

Some substances are so easily decomposed by heat, and at the same time retain water with such avidity, that it is impossible to crystallize them by any of the above processes: in these cases, crystallization may sometimes be effected by placing the solution under the exhausted receiver of an air-pump, over a surface of sulphuric acid, which, by absorbing the vapour as it rises, causes rapid evaporation without increase of temperature.

The hardness, brilliancy, and transparency of crystals, often depend upon their containing water, which sometimes exists in them in large quantities. Thus, sulphate of soda, and a few other salts, in the state of crystals, contain considerably more than half their weight; and, when exposed to a high temperature, liquefy in their own water, undergoing what is termed watery fusion. Sulphate of lime, in its crystallized form, contains about 20 per cent. of water, which it loses at a red heat, and the crystals crumble down into the white powder called Plaster of Paris. This is termed *water of crystallization;* and its proportion bears a definite relation to that of the solid salt: thus 60 parts of dry or anhydrous sulphate of magnesia are united with 63 of water, to form 123 parts of the crystallized salt; and 72 parts of anhydrous sulphate of soda require as much as 90 parts of water to form 162 parts of the ordinarily crystallized salt. Some salt part with it by simple exposure to a dry air, when they are said to *effloresce;* but there are other salts which *deliquesce*, or attract water from the atmosphere. Those crystals which effloresce by exposure to air may often be conveniently preserved, by slightly oiling their surfaces. The best method is, to soak the crystals in oil for a few hours, and then to wipe them, and put them up in bottles. Some large and transparent crystals, however, contain no combined water, as is the case with nitre, sulphate of potassa, &c.: though they often retain it mechanically, in their pores and cavities, and, consequently, when heated, fly to pieces, with a crackling noise, called *decrepitation*, which, however, sometimes merely depends upon the sudden expansion of the outer crust of the crystal.

Some salts, in consequence probably of their strong attraction for the water that retains them in solution, cannot be brought to crystallize in the ordinary way. In such cases, crystallization may sometimes be effected by the addition of substances having a strong affinity for water, by which its attraction for the dissolved matters is weakened: thus alcohol, added to certain aqueous saline solutions, produces a separation of crystals, but they are generally small and indistinct.

When two salts of different solubilities are present in the same solution, they often may be separated by crystallization, that which is least soluble constituting the earlier crop of crystals.

Crystallization is accelerated, by introducing into the solution a nucleus, or solid body, upon which the process begins; and manufacturers often avail themselves of this circumstance. Thus we see sugar-candy crystallized upon strings, and verdigris upon sticks. There are cases in which it is particularly advantageous to put a few crystals of the dissolved salt into the solution, which soon cause a crop of fresh crystals; and in some instances, if there be two salts in solution, that will most readily separate of which the crystals have been introduced. Thus if we dissolve two parts of nitre and three of sulphate of soda in five of warm water, and fill two bottles with the solution, putting into one a crystal of nitre, and into the other a crystal of sulphate of soda, and placing both in ice-cold water, nitre only will crystallize in the one, and sulphate of soda in the other.

A strong saline solution, excluded from the air, will frequently crystallize the instant that air is admitted,—a circumstance unsatisfactorily referred to atmospheric pressure. (Gay Lussac, *Ann. de Chim.* vol. lxxxvii.;) Mr. Graham (*Edinb. Phil. Trans.* 1828) ascribes it to the chemical union of air with the water holding the salt in solution. In other cases, agitation produces the same effect. These phenomena seem connected with the doctrine of latent heat, but hitherto they have only been imperfectly investigated; in some cases they have been shown by Dr. Ure to be affected by electrical changes: he found that, in the voltaic circuit, crystallization always began at the negative pole; but as alkali is there elicited, it may have tended to accelerate the process; or the acid evolved at the positive pole may have retarded it.—*Quarterly Journal*, vol. x., p. 6.

The presence of light also influences the process of crystallization. Thus we see the crystals collected in camphor bottles in druggists' windows always most copious upon the surface exposed to light; and if we place a solution of nitre in a room which has the light admitted only through a small hole in the window-shutter, crystals will form most abundantly upon the side of the basin exposed to the aperture through which the light enters, and often the whole mass of crystals will turn towards it.

Many saline solutions form arborescent crystalline pellicles, when left to spontaneous evaporation, which slowly travel up the sides of the basin, and gradually proceed down upon the outside; this process also always begins on the side nearest the light, and is often confined to it. Acetate of lime exhibits this appearance in a very beautiful manner.—Aikin's *Dict.*, Art. LIGHT.

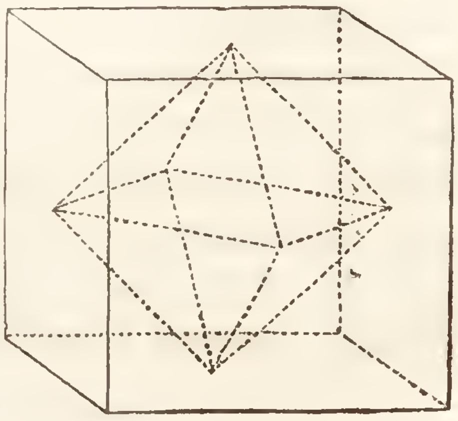
The forms of crystals are frequently modified in a remarkable manner by the medium from which they are deposited, independent of any chemical change: thus in foul and muddy liquids the crystals are usually deposited in their simplest forms; in gelatinous and saccharine solutions crystals are generally single, and remarkably sharp and regular. Common salt deposited from an aqueous solution containing urea crystallizes in octoëdra instead of cubes, which is its usual figure; and sal ammoniac, under the same circumstances, forms cubes, whereas in pure water its crystals are octoëdral. Berzelius says that very large crystals of nitre may be obtained from its solution in boiling lime water, which has no analogous effect upon other salts.

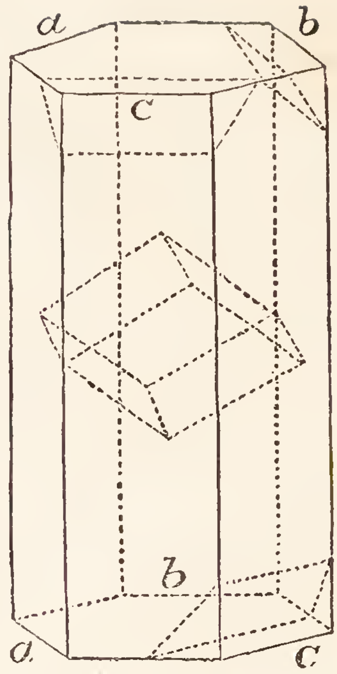
We may now proceed to notice the structure of crystallized bodies, upon which the *Theories of Crystallization* are founded. This inquiry exposes a connecting link between the Chemical and Mechanical properties of bodies.

It is commonly observed, that crystallized bodies affect one form in preference to others. The fluor spar of Derbyshire crystallizes in cubes: so does common salt. Nitre assumes the form of a six-sided prism, and sulphate of magnesia that of a four-sided prism. These forms are liable to vary. Fluor spar and salt crystallize sometimes in the form of octoëdra; and there are so many forms of carbonate of lime, that it is difficult to select that which most commonly occurs.

Romé de Lisle referred these variations of form to certain truncations of an invariable primitive nucleus; and Gahn afterwards observed, that when a piece of calcareous spar was carefully broken, all its particles were of a rhomboidal figure. This induced Bergman to suspect the existence of a primitive nucleus in all crystallized bodies (*Physical and Chemical Essays*, vol. ii. p. 1.) When Haüy entered this field of inquiry, he not only corroborated the opinions of Bergman, and submitted former hypotheses to experimental proof, but traced with much success the laws of crystallization, and pointed out the modes of transition from primitive to secondary figures.—*Traité de Minéralogie*, Paris, 1801.

Those who are in the habit of cutting and polishing certain gems, have long known that they only afford smooth surfaces when broken in one direction; and that in others the fracture is irregular and uneven. This is the case with crystallized bodies in general. If we attempt to split a cube of fluor spar with the blade of a knife, assisted by a hammer, we shall find that it will only yield kindly in the direction of the solid angles; and pursuing the division in these directions, an octoëdron will be the resulting figure, as in this diagram.





In splitting a six-sided crystal of calcareous spar, we find that of the six edges of the superior base, three alternate edges only will yield to the blow: those, for instance, marked *a*, *b*, *c*; and the division will take place in a plane inclined at an angle of 45°. The three intermediate edges resist this division. But in dissecting the inferior base of the crystal, the intermediate edges will alone yield, namely, *a*, *b*, *c*. If we continue this dissection in the same directions, we shall at length obtain the obtuse rhomboid, which is seen in this diagram in its relative situation to the including prism.

We thus then arrive at the *primitive form* of the calcareous spar; and from whatever secondary form it has been obtained, it is always a rhomboid, having obtuse angles of 105° 5′. But an obtuse rhomboid is also the primitive form of other bodies, as of pearl spar, iron spar, and tourmalin. But here the inclination of the surface points out a difference. Thus the primitive angle of pearl spar is 106° 5′, of iron spar 107°, (Wollaston, *Phil. Trans.* 1812,) and of tourmalin 113° 10′. The temperature, however, at which these measurements are taken should be noted, for it appears to affect the mutual inclinations of the planes of crystals. In the case of carbonate of lime, it amounts, according to Mitscherlich*, to as much as 8′.5. in the interval of temperature between 32° and 212°. As the temperature augments, the obtuse dihedral angles diminish; that is, the smaller axis of the rhomboid dilates more than its other diagonals, so as to cause an approach to the cubical form.

These instances show the necessity of being provided with instruments for measuring the angles of crystals with nice accuracy; they are termed *goniometers*. The simplest of these instruments consists of a protractor or semicircular scale of degrees, AA, and a small pair of compasses or nippers, BBBB, destined to receive the crystal.

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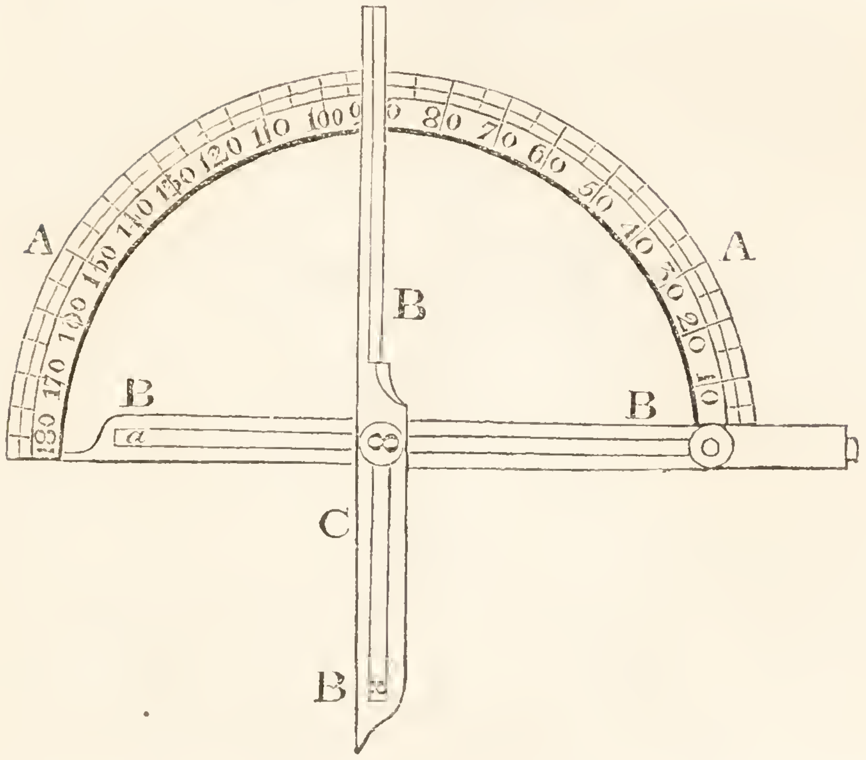
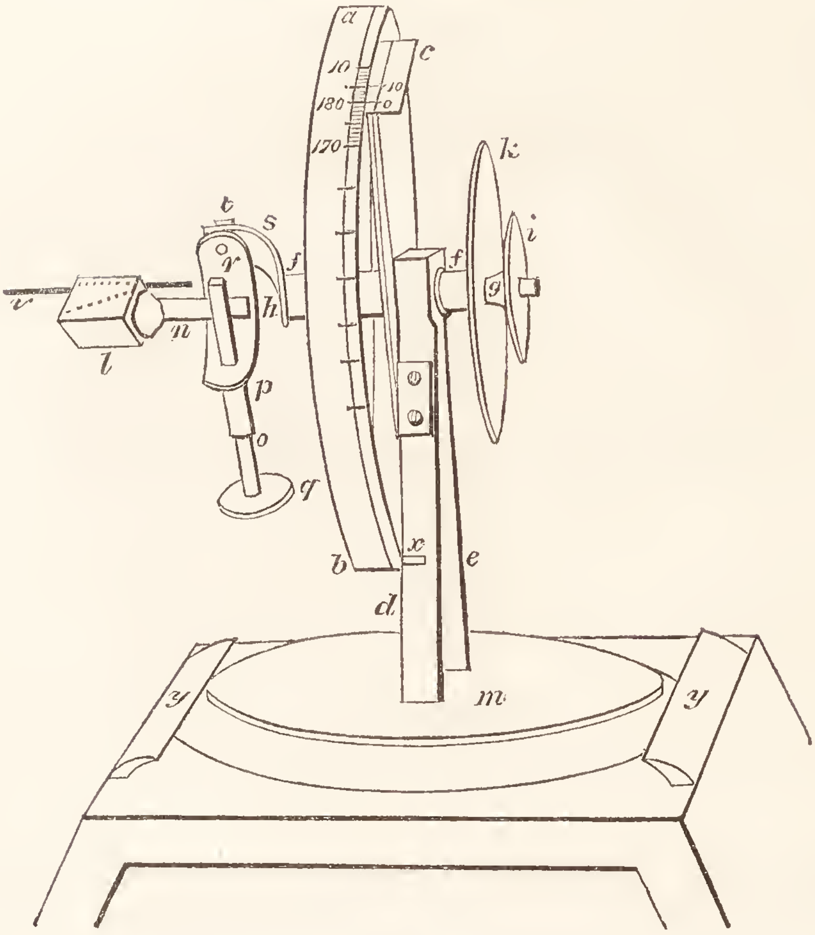
* Ann. de Ch. et Ph. xxv. 108.



The centre of the pair of compasses is made moveable, like those of the common proportional compasses, so as to permit the legs BB, and BCB, to be considerably lengthened or shortened, when the two pieces are applied to each other. The fixed leg BB, is represented as beneath the moveable one BCB, or radius, measuring 90°, and the lower end of the centre pin, which could not be shown in the wood-cut, is made to fit the hole or centre in the protractor precisely at the same time that a stud or projecting piece of brass, being admitted into the long perforation *a* of the leg BB, the piece becomes steadily attached to the protractor or semicircle, as is seen in the Figure.

The application of this instrument is obvious. The crystal to be measured is applied between the compasses, which being thus set, are applied to the protractor, and the value of the angle may be read off at the fiducial edge of the leg BCB.

The reflective goniometer, invented by Dr. Wollaston (*Phil. Trans.* 1809), is the most useful of these instruments. It enables us to determine the angles even of minute crystals with great accuracy; a ray of light reflected from the surface of the crystal being employed as radius, instead of the surface itself. Mr. W. Phillips has given the following description and practical details for the use of this instrument, in his *Introduction to Mineralogy*.



‘ *a b* is the principal circle graduated on one edge to half degrees, and divided for convenience into two parts of 180° each ; (it is graduated only in part in the above sketch.)

‘ *c* is a brass plate, screwed upon, and supported by, the pillar *d*, and graduated as a vernier.

‘ *f f* is the axle of the circle *a b*, and passes through the upper part of the two pillars *d e*, the other ends of which are inserted into a wooden base *m*.

‘ *g h* is an axle, inclosed within *f f*, and turned by means of the smallest circle *i*, which communicates a motion to all the apparatus on the left of *h*, without moving the principal circle *a b*.

‘ *k* is a circle, to which is attached the axle of the principal circle. If therefore we would move the latter, it will be done by moving *k ;* and as the axle of the principal circle includes that of the apparatus on the left of *h*, we necessarily give a motion to the whole instrument by moving the circle *k*.

‘ These two movements being understood, let us now suppose that we want to measure a crystal ; a rhomboid of carbonate of lime, for instance.

‘ Let *l* be the rhomboid, attached by means of wax to one end of a plate of brass *n;* the other end of the plate being placed in a slit in the upper part of the circular brass stem *o*, which passes through the tube *p*, to which it is so adjusted as to allow of being moved either up or down, or circularly, by means of the circle *q*.

'The tube *p* is fixed to the curved brass plate *r*, which is attached, but so as to allow of motion, to another curved plate *s*, by means of a pin *t*, the other end of the latter plate being connected with the concealed axle *g h*, to which a motion is given by turning the little circle *i*.

'By means of the pin *t* and the tube *p*, therefore, we have two motions, in addition to the two before described as belonging to the axles of the instrument. The inner axle, however, may be said to be the centre of all the motions. It will, therefore, be of advantage that the rhomboid of carbonate of lime should be placed as nearly *on a line with that axle* as possible: this will be sufficiently adjusted by means of the stem *o*, which admits of being raised or depressed at pleasure.

'The use of this instrument depends on the reflecting power of the polish on the natural planes, or fractured surfaces of minerals: and that this is in some cases very powerful, any one may convince himself by looking upon a very brilliant plane, held beneath the eye, with its edge nearly touching the lower lid, and not far distant from a window; he will then observe the reflection of the bars very distinctly.

'Let us then suppose the goniometer, as above represented, to be distant from a window from eight to twenty feet.

'Let, then, *v* be a *black line* (the use of this is essential) drawn on the wainscot between the window and the floor, and *perfectly parallel* with the horizontal bars of the window.

'If, then, the eye be placed almost close to the rhomboid *l*, a reflection of one of the bars will be seen on one of its planes.

'Let us suppose the reflection to be in the direction of the lower dotted line on the plane; and it will be clear that it cannot be parallel with the bar of the window, not being even with the black line *v*. It must therefore be adjusted. This may, perhaps, be done by slightly drawing to the left the circle *q*, which communicates motion by means of the pin *t;* or perhaps it may be done by giving a circular motion to the stem *o*. By one of these two motions, or by both, it may certainly be effected.

'If, however, the reflection appears to be like the upper dotted line, that is, parallel with the black line, *v*, we must first convince ourselves that it is so, simply by depressing the crystal a little by means of moving the little circle *i*, so as to bring the reflection *upon the black line.*

'This being adjusted, which must be done precisely, we then turn the crystal, by turning the little circle *i*, until the reflection of the *same bar* be seen on the next plane, perfectly *on a line with and upon the black line* v.

'However, in adjusting the second, we may disturb the first reflection. By perseverance it will be found that both can be adjusted by means of one or other of the movements by the stem *o*, or the pin *t*, or by the help of both, and a short experience will do away the chief difficulties.

'Both reflections being precise, we are now, by means of the circle *k*, to turn the principal circle until it is arrested by the stop *x* on the pillar *d*; it will then be found that 180 on the principal circle coincides with *o* on the vernier.

'In doing this, however, we may slightly disarrange the reflections on the plane of the crystal, which may be re-adjusted simply by moving the little circle *i*, which will not disturb the principal circle *a b*: we must be certain, however, *that* 180 *on it forms a line with* o *on the vernier, at the same time that the reflection of the bar is seen along the black line.*

'One movement more, and the measurement will have been made. Turn the circle *k*, keeping the eye almost close to the rhomboid, until the reflection of the *same bar* is seen on the adjoining plane *precisely upon the black line* v, and the operation is completed.

'It must then be observed what proportion of the principal circle has been moved. Suppose that 105 on it, be now on a line with *o* on the vernier;—it is the value of the angle. But suppose it to be a little more than 105 and less than 105½: it must then be observed *which line of the vernier touches, or forms but one line with*, another line on the principal circle: suppose it to be 5 on the vernier, the angle is then 105° 5′, which is the true value of the obtuse angle of a rhomboid of carbonate of lime.

'I have been the more particular in the above description, from being aware that the use of this elegant instrument is commonly considered to be extremely difficult, and that it is by some supposed that, in taking an angle, it is essential to keep the head in one position, which will clearly appear not to be requisite. We may, on the contrary, perform any part of the operation, and after the lapse of hours complete it.

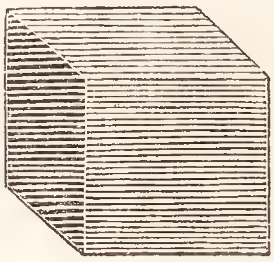
'It may not be amiss to subjoin a few hints connected with its accurate use. In the first place, it should be observed, that when the circle is arrested by the stop *x*, 180° on it is precisely on a line with *o* on the vernier; this must be exact.

'Some difficulty will at first be found in attaching the fragment of the crystal to the wax (which must be warmed) nearly in the required position. In doing this, it will be found of some advantage to hold the mineral in such a direction, that the edge between the two planes to be measured shall be in a horizontal position, and, as nearly as possible, parallel with the bar of the window. It will be best to begin with some substance which is brilliant, not more than one-third of an inch in diameter, and of which the angles are known. Fragments of transparent calcareous spar, or sulphate of barytes, are well adapted.

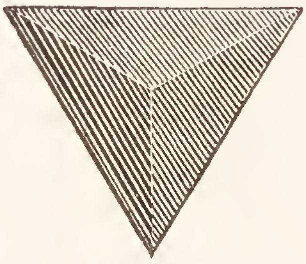
'The perfect steadiness of the instrument is essential. A small, square, and very solid table, standing firmly, will be useful: but this may not be high enough to raise the instrument to the eye of the observer without supporting the goniometer, which must be so fixed as not to shift its place while moving the circles, or by a casual touch. Supposing the table to be of the ordinary height, some support for the goniometer, a foot above it, will be requisite to elevate it to the eye of an observer while sitting. This support should be made in the form of a pyramid, with a perfectly flat base, and a truncated summit, on which the goniometer may stand, or rather may be fixed, by sliding its wooden base *m* along it; so that, in two opposite places, it shall be confined by two pieces of wood *y y*, hollowed for the purpose of receiving it. This pyramid will afford an opening in the upper part for the goniometer when out of use, while the lower may be conveniently occupied by a drawer.'

In following the method above described, Haüy obtained six *primitive* forms.

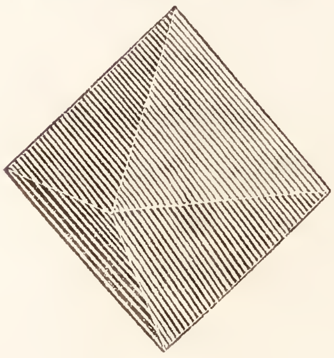
i. The cube, parallelopipedon, &c.



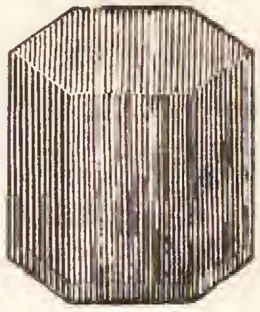
ii. The tetraëdron.



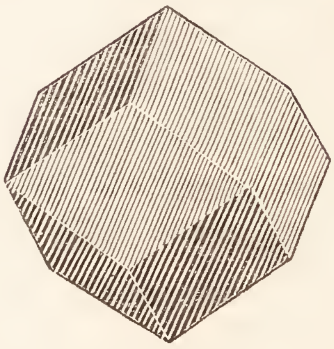
iii. The octoëdron.



iv. The hexangular prism.



v. The rhombic dodecaëdron.

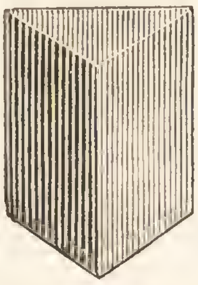


vi. The dodecaëdron with isosceles triangular faces.

These primitive forms, by further mechanical analysis, may be reduced to three *integral elements.*

i. The parallelopiped, or simplest solid, having six surfaces parallel two and two.

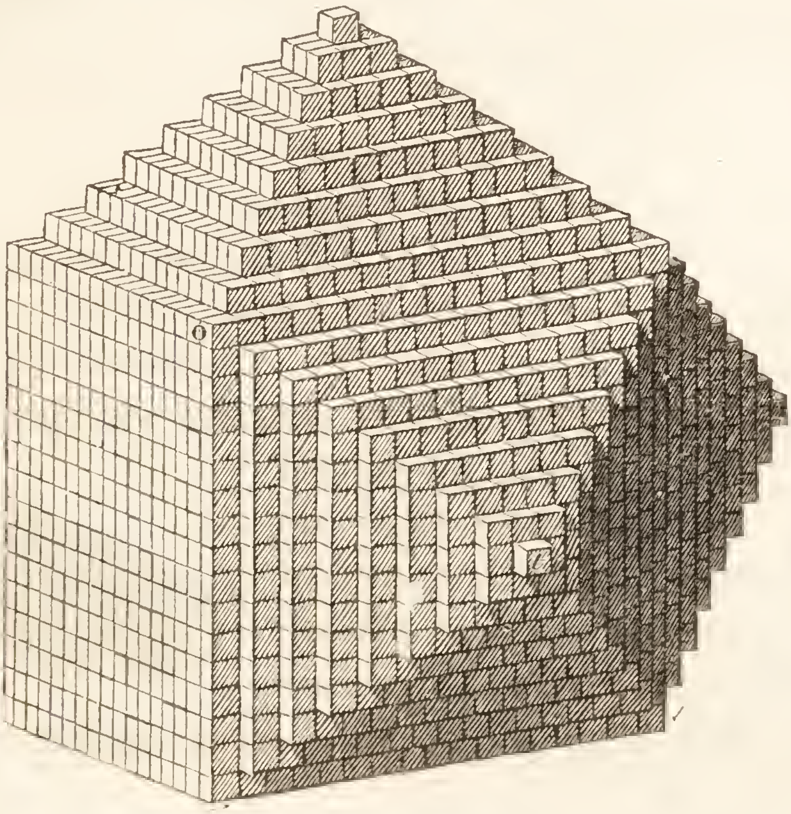
ii. The triangular, or simplest prism, bounded by five surfaces.

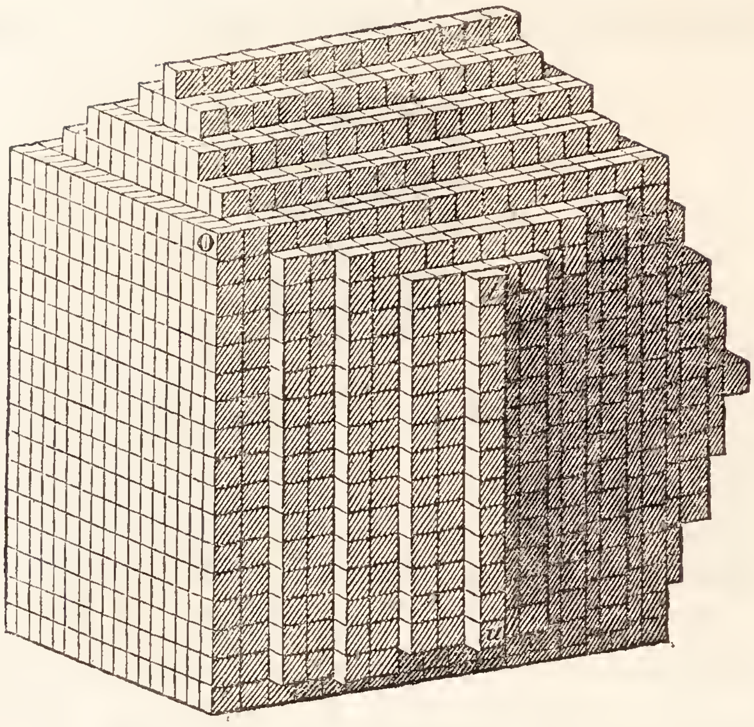


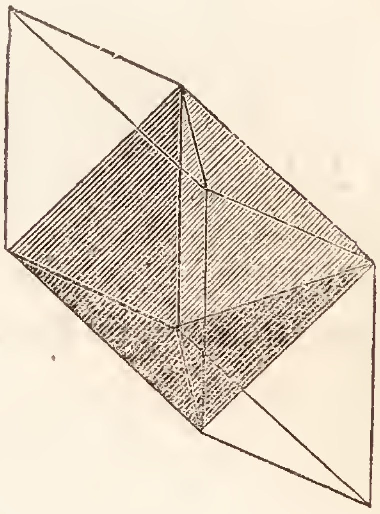
iii. The tetraëdron, or simplest pyramid, bounded by four surfaces.

Other crystallographers have taken different views of the subject of primitive forms, but as an outline only of the subject is here intended, I shall not enter into these details, but refer the reader to Mohs' *Treatise on Mineralogy*, translated by Haidinger; to Mr. Brooke's *Familiar Introduction to Crystallography*; and to Mr. Larkin's *Introduction to Solid Geometry, and to the Study of Crystallography.*

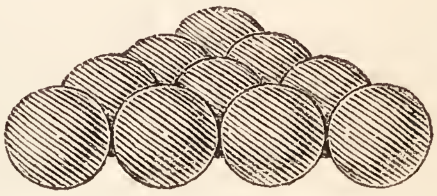
The *secondary* forms are supposed to arise from decrements of particles taking place on different edges and angles of the primitive forms. Thus a cube, having a series of decreasing layers of cubic particles upon each of its six faces, will become a dodecaëdron, if the decrement be upon the edges; but an octoëdron, if upon the angles; and by irregular, intermediate, and mixed decrements, an infinite variety of secondary forms would ensue, as the annexed figures show.



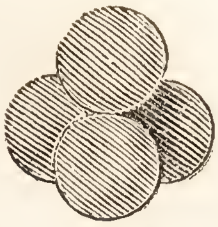


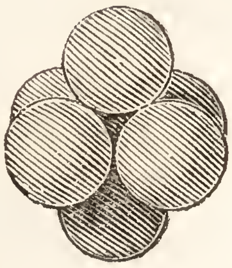


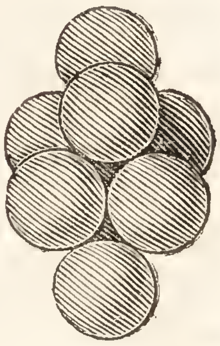
But in crystallography we meet with appearances which Haüy's theory but imperfectly explains. A slice of fluor spar, for instance, obtained by making two successive and parallel sections, may be divided into acute rhomboids; but these are not the primitive form of the spar, because, by the removal of a tetraëdron from each extremity of the rhomboid, an octoëdron is obtained. Thus, as the whole mass of fluor may be divided into tetraëdra and octoëdra, it becomes a question which of these forms is to be called primitive, especially as neither of them can fill space without leaving vacuities, nor can they produce any arrangement sufficiently stable to form the basis of a permanent crystal.



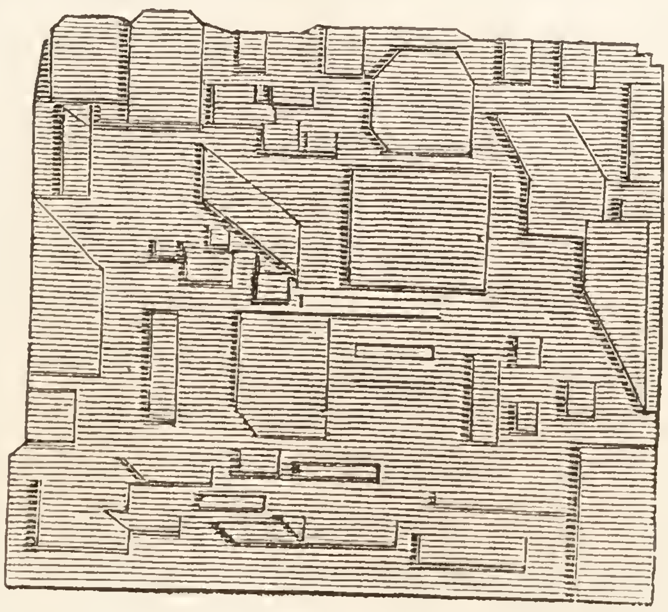
To obviate this incongruity, Dr. Wollaston (*Phil. Trans.* 1813) ingeniously proposed to consider the primitive particles as spheres, which, by mutual attraction, have assumed that arrangement which brings them as near as possible to each other. When a number of similar balls are pressed together in the same plane, they form equilateral triangles with each other; and if balls so placed were cemented together and afterwards broken asunder, the straight lines in which they would be disposed to separate, would form angles of 60° with each other. A single ball, placed any where on this stratum, would touch three of the lower balls, and the planes touching their surfaces would then include a regular tetraëdron. A square of four balls, with a single ball resting upon the centre of each surface, would form an octoëdron; and upon applying two other balls at opposite sides of this octoëdron, the group will represent the acute rhomboid. Thus the difficulty of the primitive form of fluor, above alluded to, is done away, by assuming a sphere as the ultimate molecule. By oblate and oblong spheroids other forms may be obtained.

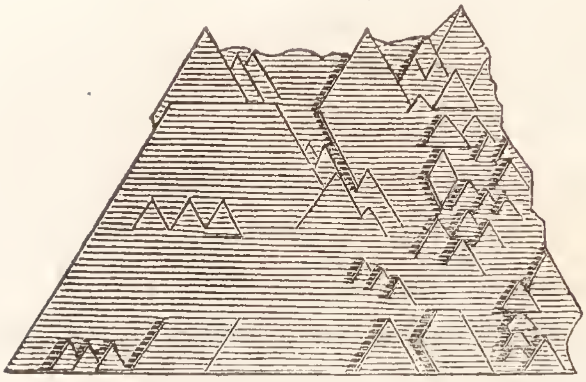






The subject of crystallization has more lately engaged the attention of Mr. J. F. Daniell, (*Quarterly Journal of Science and the Arts*, vol. i.) and his researches have produced some singular confirmations of Dr. Wollaston's hypothesis. If an amorphous piece of alum be immersed in water, and left quietly to dissolve, at the end of about three weeks we shall observe that it has been unequally acted upon by the fluid: the mass will present the forms of octoëdra, and sections of octoëdra, as it were carved or stamped upon its surface, as seen in these figures:





This appearance is produced when the attraction of the water for the solid is nearly counter-balanced by its mechanical texture. The crystals formed by this species of dissection are highly curious, from their modifications and relative positions, as the same group presents the primitive form as well as its truncations and decrements. Other salts yield other figures, and by more complicated chemical action, as of acids upon carbonate of lime, the metals, &c., analogous results are obtained. Here, then, instead of dividing a crystal by mechanical force, its structure is gradually developed by the process of solution. In these cases two circumstances are particularly remarkable: the crystals are different; and their forms vary with the different faces of the original mass. In one direction we observe octoëdra and sections of octoëdra; in another, parallelograms of every dimension, modified with certain determinate intersections.

If, in either of these positions, we turn the mass upon its axis, the same figures will be perceived at every quadrant of a circle; and if we suppose the planes continued, they will mutually intersect each other, and various geometrical solids will be constructed. In this way, alum alone furnishes octoëdrons, tetraëdrons, cubes, four and eight sided prisms either with plain or pyramidal terminations, and rhombic parallelopipedons. It is evident, then, that no theory of crystallization can be admitted, which is not founded upon such a disposition of constituent particles, as may furnish all these modifications, by mere abstraction of certain individuals from the congeries, without altering the original relative position of those which remain; and these conditions may be fulfilled by such an arrangement of spherical particles, as would arise from the combination of an indefinite number of balls endued with mutual attraction, and no other geometrical solid is adequate to the purpose; and where bodies afford crystals differing from the octoëdral series, an analogous explanation is furnished, by supposing their constituent particles to consist of oblate spheroids, whose axes bear different proportions to each other in different substances. Hence we may also conclude, that the internal structure of all crystals of the same body is alike, however the external shapes differ. In corroboration of the above hypothesis, we may remark, that the hexaëdron is, of all geometrical figures, that which includes the greatest capacity under the least surface. If, therefore, the ultimate particles of crystalline bodies be spheres or spheroids, the greatest possible number in the least space will be included in this form. It is probable that the exterior shape of every crystal is determined by the nucleus first formed by a certain definite number of particles, which, by the power of mutual attraction, overcome the resistance of the medium in which they were suspended, or from which they were separated. This number may vary with the solvent, or other contingent circumstances. Four spherical particles, thus united, would balance each other in a tetraëdral group, six in an octoëdral group, and each would present particular points of attraction to which all subsequent deposits would be directed. Now, let us imagine two nuclei formed in the same solution, whose axes run in contrary directions; their increase will consequently be in contrary directions, and each will attract a particular system of particles from the surrounding medium. If these two systems should cross each other in their course, a greater number will be brought within the sphere of mutual re-action at the point of junction, and they ought to arrange themselves in the least possible compass. The facts here answer to the theory. If we select any crystals, having others crossing them nearly at right angles, and separate them, the points of junction invariably present an hexaëdral arrangement.

In connexion with chemistry, the theory of crystallization opens a new avenue to the science, and frequently enables us to ascertain directly, that which, independent of such aids, could only be arrived at by an indirect and circuitous route. We frequently read the chemical nature of substances in their mechanical forms. To the mineralogist, an intimate acquaintance with the crystalline forms and modifications of natural bodies is essentially requisite. Indeed, the theory of crystallization may be considered as one of the great supports of that useful branch of natural history, and it is to the indefatigable exertions of Haüy that much of its present perfection is to be referred. In the arts, the process of crystallization is turned to very valuable account, in the separation and purification of a variety of substances.

Section II. Heterogeneous Attraction, or Affinity

We have hitherto considered Attraction as disposing the particles of bodies to adhere, so as to form masses or aggregates; and, in many instances, to arrange themselves according to peculiar laws, and to assume regular geometrical figures. We are now to regard this power as operating upon dissimilar particles; as presiding over the composition of bodies; and as producing their chemical varieties. This is Chemical Attraction, or Affinity.

If, into a glass vessel, exhausted of air, be introduced some sulphur and copper filings, and heat applied so as to melt the former, it will presently combine with the latter. We observe, as the results of this attraction between the sulphur and copper—1. That the substance produced has not the intermediate properties of its elements, but that it presents new characters. 2. That much heat and light are evolved during the mutual action. 3. That sulphur and copper will unite in certain proportions only.

In liquids and gases, similar changes of properties may be exhibited, and, in many cases, a change of form or state results. Thus the combination of aëriform bodies produces a solid, as when muriatic and ammoniacal gases produce the salt called muriate of ammonia. The combustion of gunpowder offers a familiar instance of the conversion of solid into aëriform matter. Gases form a liquid, as when olefiant gas is mixed with chlorine. Solids also produce liquids, as is shown by triturating crystals of Glauber's salt with nitrate of ammonia, or by rubbing together the solid amalgams of bismuth and of lead; and in the action of concentrated solutions of muriate of lime and carbonate of potassa, liquids form a solid. Liquids produce gases, as when one part of nitric acid is mixed with two of alcohol an effervescence ensues, and aëriform matter is copiously evolved.

In some cases of combination, the resulting compound differs but little from its component parts, and their leading characters are still obvious in it. This is especially remarked in solutions of different substances in water and other fluids. Salt and sugar dissolved in water, retain their saline and sweet tastes, the only physical quality that is changed being that of cohesion.

In other cases, the properties of the compound differ essentially from those of its component parts, and a series of new bodies, possessed of distinct and peculiar characters, are produced. Thus, when two volumes of nitric oxide gas are mixed with one of oxygen, an orange-coloured gas results, very sour, and soluble in water; whereas, the gases before mixture were colourless, tasteless, and insoluble in water.

Such operations are not confined to art: Nature presents them on an extended scale; and, in connexion with the functions of life, renders them subservient to the most exalted purposes.

The new chemical powers, that bodies thus acquire in consequence of combination, are often extremely remarkable, and can only be learned by *experiment*. It frequently happens that inert bodies produce inert compounds, and that active substances remain active when combined; but the reverse often occurs: thus, oxygen, sulphur, and water, in themselves tasteless and comparatively inert, produce sulphuric acid when chemically combined; and potassa, which is a powerful caustic, when combined with sulphuric acid, forms a *salt* possessed of little activity.

The colours, the specific gravity, and the temperature of bodies are also commonly altered by chemical action. Thus the *blue* infusion obtained by macerating violets in warm water is rendered *red* by acids, *green* by alkalis, and its *colour wholly destroyed* by chlorine. When equal parts of sulphuric acid and water are mixed, the resulting liquid has a specific gravity much above the mean; the temperature is also much increased; and ignition frequently attends chemical action.

As chemical action takes place among the ultimate or constituent elements of bodies, it must obviously be opposed by the cohesion of their particles, and chemical attraction is often prevented by mechanical aggregation. A piece of the metal antimony, put into the gas called chlorine, is only slowly and superficially acted upon; but if the mechanical aggregation be previously diminished, by reducing the metal to powder, it in that state rapidly unites with the gas, and burns the instant that it is introduced.

Heat increases the chemical energies of bodies. Its effects are sometimes only referable to the diminution of adhesion by expansion or liquefaction; but in other cases they are peculiar and complicated, and probably concerned in modifying the electrical energies of the acting substances.

Different bodies are possessed of different attractive powers; and if several be brought together, those which have the strongest mutual affinities enter first into union. Thus, if nitric acid be poured upon a mixture of lime and magnesia, it dissolves the former in preference to the latter earth. The knowledge of this fact enables us to separate bodies when united, or to perform the process of *decomposition*. Thus, if we add an aqueous solution of lime to a solution of magnesia in nitric acid, the latter earth is thrown down or precipitated, and the lime occupies its place in the acid.

Upon this principle tables of attraction have been constructed, the substance whose affinities are to be represented being placed at the head of a column, and the bodies with which it combines beneath it, in the order of their respective attractions (see *Prefatory History of Chemistry*); thus the affinity of sulphuric acid for several bases would be shown as follows:—

SULPHURIC ACID.

Baryta.
Strontia.
Potassa.
Soda.
Lime.
Magnesia.
Ammonia.

From this table it would appear that baryta separates sulphuric acid from its compounds with all the inferior substances, and that ammonia is separated by all that are above it; there are, however, many circumstances which interfere with the usefulness and accuracy of such tables, and in some cases there are apparent anomalies in the mutual agencies of bodies which wholly subvert this order of arrangement. This is especially the case in the decomposition of certain insoluble compounds by soluble salts. One of these, originally noticed by M. Dulong, (*Ann. de Chim.* lxxxii., Nicholson's *Journ.* 35 and 36,) has been pointed out by Mr. R. Phillips (*Journal of Science and the Arts*, vol. i., p. 80). He found that, on boiling carbonate of baryta in a solution of sulphate of potassa, sulphate of baryta and carbonate of potassa were formed; and he also found that, on reversing the experiment, by boiling sulphate of baryta in a solution of carbonate of potassa, carbonate of baryta and sulphate of potassa were produced.

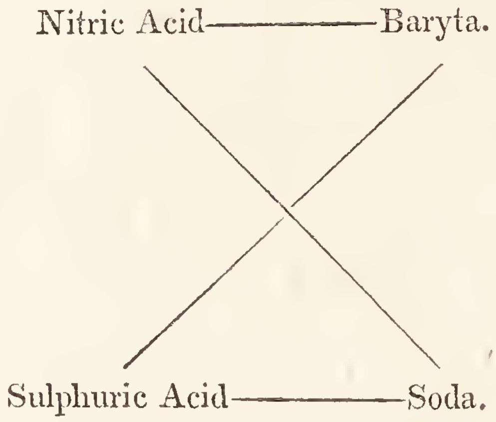
The general inferences deducible from M. Dulong's researches upon this subject are the following. 1. That all the insoluble salts are decomposed by the carbonates of potassa or soda; but that a mutual exchange of principles of these salts cannot in any case be complete. 2. That all the soluble salts, of which the acid forms with the base of the insoluble carbonate an insoluble salt, are decomposed by these carbonates until the decomposition has reached a certain limit which it cannot pass. (Ure's *Dict.*—Art. ATTRACTION.)

Decomposition is effected under a variety of circumstances, and by many methods; but it is commonly described by chemists as SIMPLE and COMPLEX, or SINGLE and DOUBLE.

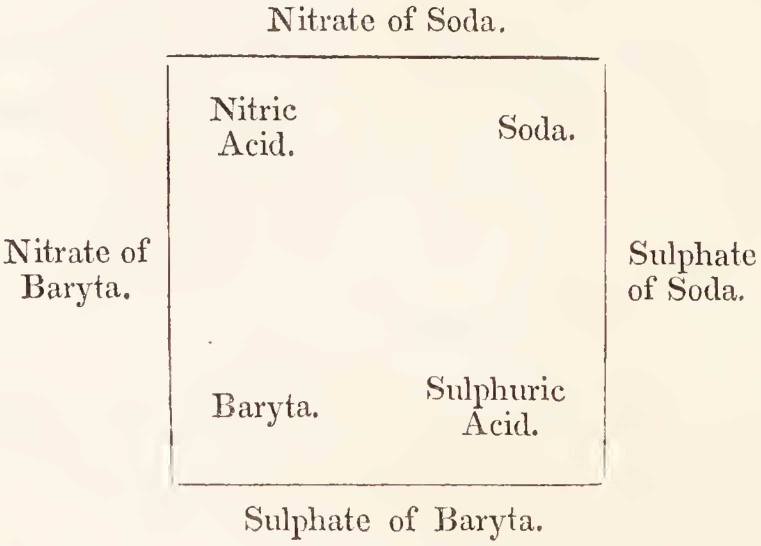
In cases of simple attraction or affinity, one body separates another from its combination with a third. Thus, when potassa is added to a solution of sulphate of zinc (composed of sulphuric acid and oxide of zinc), the oxide of zinc is separated, and sulphate of potassa is produced; or when sulphuric acid is dropped into a solution of baryta, sulphate of baryta is precipitated.

In cases of double decomposition, two new compounds are produced; as when a solution of nitrate of baryta is mixed with a solution of sulphate of soda, the results are a precipitate of sulphate of baryta, and a solution of nitrate of soda.

These cases of double decomposition are sometimes conveniently illustrated by diagrams, which may either be constructed so as merely to show the result of the change, or, where required, they may also exhibit the composition of the acting bodies. In the case just alluded to, the substances before mixture are shown by parallel lines, and after mixture by diagonal lines.



Or a more complete view of the change is given in the following diagram, where the bodies before mixture are placed upon the outside of the perpendicular lines; their component parts are shown within them; and the new results on the outside of the horizontal lines.



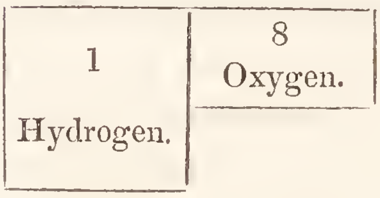
In double decompositions, in consequence of more than one attraction being brought into play, we often effect changes which are unattainable by single decomposition. Thus, if we put zinc into water, no change occurs; but if we add sulphuric acid, a portion of the water is immediately resolved into its elements; one of these, *hydrogen*, is evolved in the state of gas; and the other, *oxygen*, unites with the zinc to form oxide of zinc, which combines with the sulphuric acid. Thus the strong attraction of sulphuric acid for oxide of zinc appears to influence the decomposing power of the metal, and the experiment furnishes an instance of what has been called *predisposing affinity*; but it is probable that electrical actions are here concerned.

It is obvious, from the uniform results of chemical action, that affinity must be governed by certain definite laws, by which its results are determined, and upon which its uniformity depends. Thus the composition of the sulphate of baryta, formed in the above instances by single and double decomposition, is found in all cases perfectly identical: it contains 78 parts of baryta united with 40 of sulphuric acid; and in whatever way sulphate of baryta is formed, or in whatever part of the world it occurs as a natural product, its elements are always united exactly in the above proportions. Attention was first called to this subject by Mr. Higgins in 1789.—(*Comparative View of the Phlogistic and Antiphlogistic Theories.*) He conceived that chemical attraction only prevailed between the ultimate particles of simple elementary matter, and between compound atoms; and, in applying this idea to chemical theory, he expressed by numbers the relative forces of attraction subsisting between the different kinds of ultimate particles and atoms of matter.

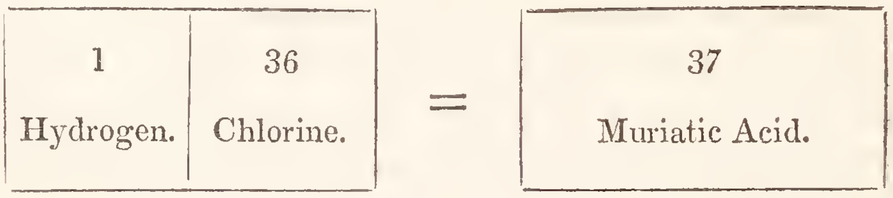
These views were subsequently extended and improved by Mr. Dalton, and have since engaged the attention of some of the most eminent chemical philosophers; among whom we may enumerate Gay-Lussac and Berzelius, Davy, Wollaston, and Thomson.—See *History of Chemistry.*

This *atomic doctrine*, or *theory of definite proportionals*, has been much blended with hypothetical views; but it will be most satisfactorily and usefully considered as an independent collection of facts.

When bodies unite so as to form one compound only, that compound always contains the same relative proportions of its components; and where two bodies unite in more than one proportion, the second, third, &c. proportions, are multiples or divisors of the first. This law is well exhibited in the combinations of gaseous bodies. These are seen to unite in simple ratios of volume. Water is composed of hydrogen and oxygen, and 1 part by weight of the former gas, unites to 8 of the latter. The specific gravity of hydrogen, compared with that of oxygen, is as 1 to 16; it is obvious, therefore, that one volume of hydrogen unites to half a volume of oxygen, and that the composition of water will be represented by weight and volume thus:



Muriatic acid gas consists of 1 part by weight of hydrogen and 36 by weight of chlorine. The relative specific gravities of these gases are as 1 to 36. It is obvious, therefore, that they combine in equal volumes, and that muriatic acid gas may be thus represented:



Carbonic acid unites to potassa in two proportions, and forms two definite compounds. In the one, 70 parts of potassa are combined with 30 of carbonic acid: in the other, 70 of potassa are united to 60 of carbonic acid. (Wollaston, *Phil. Trans.* 1808.)

Lead combines with oxygen in three proportions: the first compound consists of 104 lead + 8 oxygen; the second, of 104 + 12; the third, of 104 + 16.

All cases of chemical combination, in which the qualities of the component parts are no longer to be detected in the compound, or in which a neutral body is produced, are obedient to these laws of union: but in some instances bodies may be said to unite in all proportions, as water and alcohol, &c. Other bodies combine in all proportions up to a certain point only, and beyond that, combination no longer ensues. Thus water will take up successive portions of common salt, until at length it refuses to take up more, or is *saturated;* and this always occurs when the water has dissolved a definite weight of the salt.

The term *neutralization* is applied to cases in which bodies mutually disguise each other's properties, as is especially exemplified in the union of acids with alkalis; as of sulphuric acid, for instance, with solution of potassa. The acid reddens violet juice, and is sour. The potassa converts the blue to green, and is acrid. If the acid solution be gradually added to the alcaline, we shall find that, at a certain point, the taste will neither be acid nor acrid, but slightly saline and bitter, nor will there be any effect produced upon the vegetable blue. Thus the acid is neutralized by the alkali, and the compound has been termed a *neutral salt.*

When we have ascertained the proportion in which any two or more bodies of one class *a b c*, neutralize another body, *x*, of a different class, it will be found that the same relative proportion of *a b c*, &c., will be required to neutralize any other body of the same class, as *x*. Thus, since 100 parts of sulphuric acid, and 68 (omitting fractions) of muriatic acid, neutralize 118 of potassa, and since 100 of sulphuric acid neutralize 71 of lime, we may infer that 68 of muriatic acid will also neutralize 71 of lime.

If the quantities of two bodies A and B, that are necessary to saturate a given weight of a third body, be represented by *q* and *r*, these quantities may be called *equivalents*. Thus, in the above example, 100 parts of sulphuric acid and 68 of muriatic acid are *equivalents* of each other. A column or table of equivalent numbers is of great use in chemical calculations. By adapting a table of this sort to a moveable scale, on the principle of Gunter's sliding rule, Dr. Wollaston has constructed a *logometric scale of chemical equivalents*, which is capable of solving with great facility many problems of chemistry.—(*Phil. Trans.* 1814.)

It would be premature further to pursue the subject of the atomic theory, and of the laws which influence the combination of bodies, in the present section, by reference to facts and statements which are reserved for succeeding pages: the reader who is desirous of a more general account of the origin and progress of this department of chemical philosophy, will find an excellent abstract of its history in Dr. Turner's *Elements of Chemistry**.

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* Second edition, p. 147.

By prosecuting chemical analysis, we arrive at a certain number of *principles* or *elements;* that is, of bodies which have not hitherto been decomposed.

The nature of compound bodies is demonstrated by two kinds of proof—*synthesis* and *analysis.* Synthesis consists in effecting the chemical union of two or more bodies, which by analysis are again separated from each other. The term *proximate analysis* has been applied to the separation of two bodies which are themselves compounded; and *ultimate analysis* to the further separation of these compounds into their components. The composition of blue vitriol is *synthetically* demonstrated by *uniting* sulphuric acid to oxide of copper—*analytically*, by *separating* these *proximate* elements from each other. But the sulphuric acid consists of sulphur and oxygen; and oxide of copper consists of copper and oxygen: consequently, we should say, that the *ultimate* component parts of blue vitriol are copper, sulphur, and oxygen.

Section III. HEAT.

HEAT may be considered as a power opposed to attraction, for it tends to separate the particles of bodies; and whenever a body is heated, it is also expanded. Expansion is the most obvious and familiar effect of heat; and it takes place, though in different degrees, in all forms of matter. Solids are the least expansible,—liquids expand more readily than solids,—and gases or aëriform bodies more than liquids.

When a body has been expanded by heat, it regains its former dimensions, or *contracts*, when cooled to its former temperature.

Different bodies expand differently when equally heated. The metals are the most expansible solids; but among them, zinc expands more than iron, and iron more than platinum.

The following Table shows the relative expansibility of some of the metals, when their temperature is raised from the freezing to the boiling point of water.

	Temperature.	
	32°	212°
Platinum . .	120000	120104
Steel . . .	120000	120147
Iron . . .	120000	120151
Copper . .	120000	120204
Brass . .	120000	120230
Tin . . .	120000	120290
Lead . . .	120000	120345
Zinc . . .	120000	120360

In the range of temperature between 32° and 212°, the expansion is apparently nearly equable; but the experiments of Dulong and Petit (*Ann. de Chim. et Phys.*, and *Annals of Philosophy*, xiii. 164,) show, that the rate of expansion increases with the temperature; and Dr. Ure's experiments have proved, in regard to zinc, that that metal permanently elongates after frequent heating and cooling. "It would seem," he says, "that the plates composing this metal, in sliding over each other, by the expansive force of heat, present such an adhesive friction as to prevent their entire retraction." In regard to the unequal expansion of bodies at different temperatures, the same philosopher remarks, that it is probable every species of matter follows an increasing rate in its enlargement by caloric, for each portion that enters a body must weaken cohesion, and therefore render the operation of the next portion that is introduced more efficacious.

The following copious Table of the linear dilatation of solids by heat is compiled by Dr. Ure, and published in his *Chemical Dictionary*, Art. Caloric.

Dimensions which a bar takes at 212°, whose length at 32° is 1.000000.			Dilatation in Vulgar Fractions.
Glass tube	Smeaton	1.00083333	
do.	Roy	1.00077615	
do.	Deluc's mean	1.00082800	
do.	Dulong and Petit	1.00086130	$\frac{1}{1116}$
do.	Lavoisier and Laplace,	1.00081166	$\frac{1}{1143}$
Plate glass	do. do.	1.000890890	$\frac{1}{1122}$
do. crown glass	do. do.	1.00087572	$\frac{1}{1142}$
do. do.	do. do.	1.00089760	$\frac{1}{1114}$
do. do.	do. do.	1.00091751	$\frac{1}{1090}$
do. rod	Roy	1.00080787	
Deal	Roy, as glass	....	
Platina	Borda	1.00085655	
do.	Dulong and Petit	1.00088420	$\frac{1}{1131}$
do.	Troughton	1.00099180	
do. and glass	Berthoud	1.00110000	
Palladium	Wollaston	1.00100000	
Antimony	Smeaton	1.00108300	
Cast-iron prism	Roy	1.00110940	
Cast-iron	Lavoisier, by Dr. Young,	1.00111111	
Steel	Troughton	1.00118990	
Steel rod	Roy	1.00114470	
Blistered steel	Phil. Trans. 1795, 428	1.00112500	
do.	Smeaton	1.00115000	
Steel not tempered	Lavoisier and Laplace,	1.00107875	$\frac{1}{927}$
do. do. do.	do. do.	1.00107956	$\frac{1}{926}$
do. tempered yellow	do. do.	1.00136900	
do. do. do.	do. do.	1.00138600	
do. do. do. at a higher heat	do. do.	1.00123956	$\frac{1}{807}$
Steel	Troughton	1.00118980	
Hard steel	Smeaton	1.00122500	
Annealed steel	Muschenbroek	1.00122000	
Tempered steel	do.	1.00137000	
Iron	Borda	1.00115600	
do.	Smeaton	1.00125800	
Soft iron forged	Lavoisier and Laplace,	1.00122045	
Round iron, wire-drawn	do. do.	1.90123504	
Iron wire	Troughton	1.00144010	
Iron	Dulong and Petit	1.00118203	$\frac{1}{846}$
Bismuth	Smeaton	1.00139200	
Annealed gold	Muschenbroek	1.00146000	
Gold	Ellicot, by comparison,	1.00150000	
do. procured by parting	Lavoisier and Laplace,	1.00146606	$\frac{1}{682}$
do. Paris standard, unannealed	do. do.	1.00155155	$\frac{1}{645}$
do. do. annealed	do. do.	1.00151361	$\frac{1}{661}$
Copper	Muschenbroek	1.0019100	
do.	Lavoisier and Laplace,	1.00172244	$\frac{1}{581}$
do.	do. do.	1.00171222	$\frac{1}{584}$
do.	Troughton	1.00191880	
do.	Dulong and Petit	1.00171821	$\frac{1}{582}$

Dimensions which a bar takes at 212°, whose length at 32° is 1.000000.

			Dilatation in Vulgar Fractions.
Brass	Borda	1.00178300	
do.	Lavoisier and Laplace,	1.00186671	
do.	do. do.	1.00188971	
Brass scale, supposed from Hamburg,	Roy	1.00185540	
Cast brass	Smeaton	1.00187500	
English plate-brass, in rod	Roy	1.00189280	
English plate-glass, in a trough form,	Roy	1.00189490	
Brass	Troughton	1.00191880	
Brass wire	Smeaton	1.00193000	
Brass	Muschenbroek	1.00216000	
Copper 8, tin 1	Smeaton	1.00181700	
Silver	Herbert	1.00189000	
do.	Ellicot, by comparison,	1.0021000	
do.	Muschenbroek	1.00212000	
do. of cupel	Lavoisier and Laplace,	1.00190974	$\frac{1}{524}$
do. Paris standard	do. do.	1.00190868	$\frac{1}{524}$
Silver	Troughton	1.0020826	
Brass 16, tin 1	Smeaton	1.00190800	
Speculum metal	do.	1.00193300	
Spelter solder; brass 2, zinc 1	do.	1.00205800	
Malacca tin	Lavoisier and Laplace,	1.00193765	$\frac{1}{516}$
Tin from Falmouth	do. do.	1.00217298	$\frac{1}{462}$
Fine pewter	Smeaton	1.00228300	
Grain tin	do.	1.00248300	
Tin	Muschenbroek	1.00284000	
Soft solder; lead 2, tin 1	Smeaton	1.00250800	
Zinc 8, tin 1, a little hammered	do.	1.00269200	
Lead	Lavoisier and Laplace,	1.00284836	$\frac{1}{351}$
do.	Smeaton	1.00286700	
Zinc	do.	1.00294200	
Zinc, hammered out ½ an inch per foot,	do.	1.00301100	
Glass, from 32° to 212°	Dulong and Petit	1.00086130	$\frac{1}{1161}$
do. from 212° to 392°	do. do.	1.00091827	$\frac{1}{1089}$
do. from 392° to 572°	do. do.	1.000101114	$\frac{1}{987}$

The last two measurements by an air thermometer.

To obtain the expansion in volume, multiply the above decimal quantities by three, or divide the denominators of the vulgar fractions by three; the quotient in either case is the dilatation sought.

There are many mechanical operations in which the expansion and contraction of metals produce very important effects, and it becomes necessary to determine their operation with great exactness. This is often the case in regard to the change of dimensions to which astronomical instruments are liable, and the rate of going of clocks and watches is materially affected by the same cause. In regulating the length of the seconds pendulum, an exact acquaintance with the dilatation of metals is essential, for when the bob is let down $\frac{1}{100}$ of an inch, the clock loses ten seconds in twenty-four hours; hence the elongation of $\frac{1}{1000}$ of an inch will cause it to lose one second per day, and a change of temperature equal to 30° of Fahrenheit will alter its length about $\frac{1}{5000}$ part, and occasion an error in the rate of going, of eight seconds per day. Variations of temperature also occasion variations in the oscillations of the balance-wheels of watches. These effects are obviated by various compensating apparatus, which are described in works on practical horology.—See *Reid on Clock and Watchmaking*, p. 257.

Liquids differ also in their relative expansibilities: ether is more expansible than spirit of wine, and spirit more than water, and water more than mercury. Those liquids are generally most expansible which boil at the lowest temperature.

The following Table shows the rate of expansion of several liquids:

Temp.	Mercury.	Linseed Oil.	Sulphuric Acid.	Nitric Acid.	Water.	Oil of Turpentine	Alcohol.
32°	100000	100000	—	—	—	—	100000
40	100081	—	99752	99514	—	—	100539
50	100183	—	100000	100000	100023	100000	101105
60	100304	—	100279	100486	100091	100460	101688
70	100406	—	100558	100990	100197	100993	102881
80	100508	—	100806	101530	100332	101471	102890
90	100610	—	101054	102088	100694	101931	103517
100	100712	102760	101317	102620	100908	102446	104162
110	100813	—	101540	103196	—	102943	—
120	100915	—	101834	103776	101404	103421	—
130	101017	—	102097	104352	—	103954	—
140	101119	—	102320	105132	—	104573	—
150	101220	—	102614	—	102017	—	—
160	101322	—	102893	—	—	—	—
170	101424	—	103116	—	—	—	—
180	101526	—	103339	—	—	—	—
190	101628	—	103587	—	103617	—	—
200	101730	—	103911	—	—	—	—
212	101835	107250	—	—	104557	—	—

The expansion of liquids is not equable for equal additions of heat at different temperatures. Thus the addition of 5° of heat to alcohol at 40°, will produce a less relative increase of bulk than the same addition of heat to alcohol of 100°; and in general, the nearer a liquid approaches its boiling point, the greater is its expansibility. Those liquids, therefore, appear most equably expansible which have the highest boiling points; and hence one of the great advantages of mercury, as will presently be seen, in constructing thermometers.

In all pure gaseous bodies, the rate of expansion for similar increase of temperature is similar; an important fact, originally established by Mr. Dalton: 100 measures of air, when heated from the freezing to the boiling point of water, suffer an increase in bulk = 37.5 parts at mean pressure.

The experiments of Gay Lussac have proved that steam, and all vapours, when heated out of contact of their respective fluids, are subject to laws of expansion similar to those of air; —hence the following Table, showing the changes of bulk suffered by 100,000 parts of air at all temperatures between 32° and 212°, will apply equally to all gases and vapours, and will often be found useful to the practical chemist.

Temp.	Bulk.	Temp.	Bulk.	Temp.	Bulk.	Temp.	Bulk.	Temp.	Bulk.
32°	100000	49°	103536	65°	106864	81°	110192	97°	113520
33	100208	50	103749	66	107072	82	110400	98	113728
34	100416	51	103952	67	107280	83	110608	99	113936
35	100624	52	104166	68	107488	84	110816	100	114144
36	100833	53	104368	69	107696	85	111024	110	116224
37	101040	54	104576	70	107904	86	111232	120	118304
38	101248	55	104791	71	108112	87	111440	130	120384
39	101459	56	104992	72	108320	88	111648	140	122464
40	101666	57	105200	73	108528	89	111856	150	124544
41	101872	58	105408	74	108736	90	112064	160	126624
42	102080	59	105616	75	108944	91	112272	170	128704
43	102290	60	105824	76	109152	92	112480	180	130784
44	102496	61	106032	77	109360	93	112688	190	122864
45	102708	62	106240	78	109568	94	112896	200	134944
46	102916	63	106448	79	109776	95	113104	210	137024
47	103124	64	106656	80	109984	96	113312	212	137440
48	103333								

The rate of expansion of atmospheric air at temperatures above 212°, has been investigated by Dulong and Petit (*Ann. de Chim. et Phys.*, vii. 120). The following Table exhibits the results of their observations (*Turner's Elements, 2nd Ed.* p. 34).

Temperature by the Mercurial Thermometer. Fahr.	Centig.	Corresponding Volumes of a given Volume of Air.
— 33	— 36	0.8650
32	0	1.0000
212	100	1.3750
302	150	1.5576
392	200	1.7389
482	250	1.9189
572	300	2.0976
680	360	2.3125

As heat increases the bulk of all bodies, it is obvious that change of temperature is constantly producing changes in their density or specific gravity, as may be easily demonstrated in fluids where there is freedom of motion among the particles. If I apply heat to the bottom of a vessel of water, the heated part expands and rises, while a cold or denser stratum occupies its place. In air, similar currents are continually produced, and the vibratory motion observed over chimney-pots, and slated roofs which have been heated by the sun, depends upon this circumstance: the warm air rises, and its refracting power being less than that of the circumambient colder air, the currents are rendered visible by the distortion of objects viewed through them.

The ventilation of rooms and buildings can only be perfectly effected by suffering the heated and foul air to pass off through apertures in the ceiling, while fresh air, of any desired temperature, is admitted from below. Various contrivances have been resorted to, to prevent the passage of cold air from above downwards through the ventilator, which can only be completely effected by keeping the ventilating tubes at a higher temperature than the surrounding air; heating them, for instance, by steam; passing them through a fire; or placing a lamp beneath them, of sufficient dimensions to cause a strong current upwards: upon the latter principle, the gas chandeliers in our theatres, being placed under a large funnel which passes through the roof into the outer air, may be made to operate as very powerful ventilators, their own heat and smoke passing off with a large proportion of the air of the house. (*Quarterly Journal*, v.) The method of warming and ventilating houses and other buildings has been ably investigated and greatly improved by Mr. Sylvester.—See his account of the Derby Infirmary, and the *Quarterly Journal*, xi. 230.

There is only one strict exception to the general law of expansion by heat, and contraction by cold; this is in the case of water, which expands considerably when it approaches its freezing point. Water has attained its maximum of density at 40°; Mr. Crichton's experiments place the maximum of density at 42° (*Ann. of Phil.* N. S. v. 491); and if it be cooled below 44°, it expands as the temperature diminishes, as it does when heated above 40°; and the rate of this expansion is equal for any number of degrees above or below this maximum of density, so that the bulk of water at 32° and at 48° will be the same. Accordingly, if two thermometer tubes, one containing spirit of wine, and the other water, be immersed into melting snow, the former will sink till it indicates 32°; but the latter, when it has attained 40°, begins to expand, and continues so to do till it freezes.

This anomaly in respect to water is productive of very important consequences, in preserving the depths of rivers and lakes of a temperature congenial to their inhabitants.—See *Prefatory History of Chemistry*.

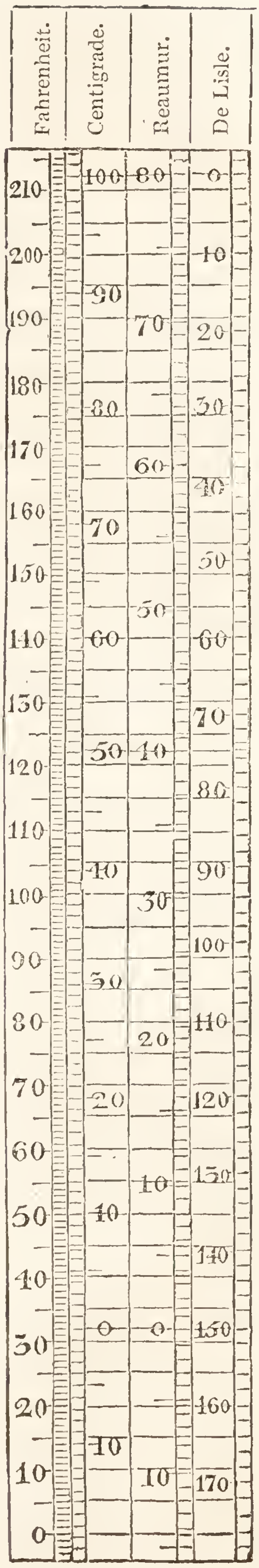
There are many liquids which suffer considerable expansion in passing into the solid state. This is the case with the greater number of saline solutions, and remarkably with water; it seems connected with the phenomena of crystallization, and is referable to a new arrangement of particles. That the force with which water expands in the act of freezing is very considerable, is shown by the rupture of leaden and iron pipes in which it is suffered to freeze. Dr. Thomson has shown that water, in freezing, suffers a much greater expansion than when heated from the freezing to the boiling point; for the specific gravity of water at 60° being = 1, that of ice at 32° is only 0.92. Of the metals, Reaumur found that cast-iron, bismuth, and antimony, expanded in becoming solid; the rest contracted. Mercury suffers a remarkable contraction in the act of freezing.

If we mix equal quantities of the same fluid at different temperatures, the cold portion will expand as much as the hot portion contracts, and the resulting temperature is the mean; so that it appears, that as much heat as is lost by the one portion is gained by the other. Upon this principle *thermometers* are constructed. A common thermometer consists of a tube terminated at one end by a bulb, and closed at the other. The bulb and part of the tube are filled with a proper liquid, generally mercury, and a scale is applied, graduated into equal parts. Whenever this instrument is applied to bodies of the same temperature, the mercury, being similarly expanded, indicates the same degree of heat.

The great advantage of mercury as a thermometric fluid is, that the range of temperature between its freezing and boiling points is very considerable, and its expansion within that range tolerably equable. In consequence of the greater expansibility of alcohol, it is well adapted for common atmospheric thermometers, where large degrees are required; and, as it has never been frozen, it is peculiarly calculated for the determination of low temperatures, although its rate of contraction in excessive degrees of cold is not sufficiently determined to enable us to rely with accuracy upon its indications, which are also much affected by the strength or nature of the alcohol employed. The low temperature at which it boils, and its irregular expansion upon approaching its boiling point, render it quite unfit for a measure of temperatures above 100°.

In dividing the scale of a thermometer, the two fixed points usually resorted to are the freezing and boiling of water, which always take place at the same temperature, when under the same atmospheric pressure. The intermediate part of the scale is divided into any convenient number of degrees; and it is obvious, that all thermometers thus constructed will indicate the same degree of heat when exposed to the same temperature. In the centigrade thermometer, this space is divided into 100°: the freezing of water being marked 0°, the boiling point 100°. In this country we use Fahrenheit's scale, of which the 0 is placed at 32° below the freezing of water, which, therefore, is marked 32°, and the boiling point 212°, the intermediate space being divided into 180°. Another scale is Reaumur's; the freezing point is 0°, the boiling point 80°. These are the principal thermometers used in Europe.

Directions for constructing and filling thermometer tubes will be found in Dr. Henry's *Elements of Chemistry*, and in Dr. Ure's *Dictionary* (Art. Thermometer); but the chemist is scarcely ever called upon to prepare them for himself; and if he attempt it without much practice, he will inevitably fail. Nor is it easy to purchase a really good thermometer, which, in consequence of the skill and time required in making it, becomes a somewhat costly instrument. The laboratory should be provided with one excellent standard instrument, which will serve as a check upon the correctness of those in common use; for it rarely happens that we can purchase two thermometers which exactly correspond in the different parts of their scales. Upon the general subject of the measure of temperature, and of the circumstances which influence the accuracy of thermometric researches, the reader is referred to Dr. Ure's Memoir in the *Phil. Trans.* 1818, and to that of MM. Dulong and Petit (*Ann. de Chim. and Phys.* vol. vii.)



Each degree of Fahrenheit's scale is equal to $\frac{4}{9}$ of a degree on Reaumur's: if, therefore, the number of degrees of Fahrenheit's scale, above or below the freezing of water, be multiplied by 4, and divided by 9, the quotient will be the corresponding degree of Reaumur.

Fahrenheit. Reaumur.

$68° - 32° = 36 \times 4 = 144 \div 9 = 16°$

$212° - 32° = 180 \times 4 = 720 \div 9 = 80°$

To reduce the degrees of Reaumur to those of Fahrenheit, they are to be multiplied by 9, and divided by 4.

Reaumur. Fahrenheit.

$16° \times 9 = 144 \div 4 = 36° + 32° = 68$

$80° \times 9 = 720 \div 4 = 180° + 32° = 212$

Every degree of Fahrenheit is equal to $\frac{5}{9}$ of a degree on the centigrade scale ; the reduction, therefore, is as follows :—

Fahrenheit. Centigrade.

$$212-32=180\times 5=900\div 9=100^\circ$$

Centigrade. Fahrenheit

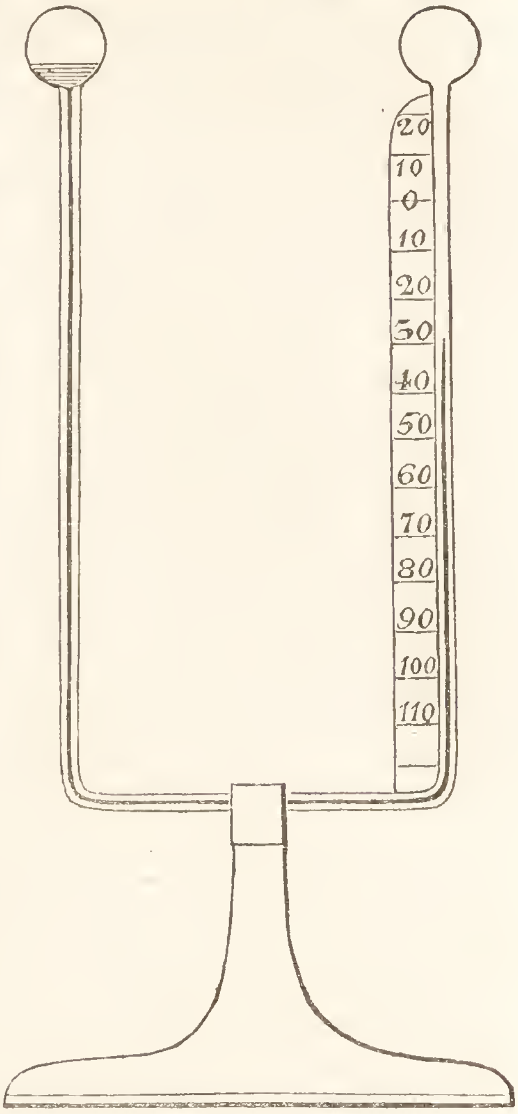
$$100\times 9=900\div 5=180+32=212^\circ$$

On the preceding page is a comparative table of the different thermometrical scales, including De Lisle's, in which the graduation commences with the boiling point, which is marked 0°, and the freezing 150°.

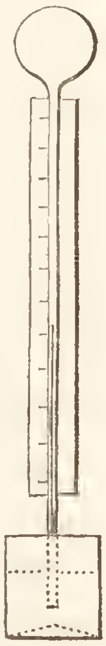
For the measurement of temperatures higher than the boiling point of mercury, Mr. Daniell's pyrometer is the most unexceptionable instrument, and is not liable to those sources of fallacy which render the results obtained by Mr. Wedgewood's clay pyrometer so uncertain and equivocal. This instrument is described and represented in the *Quarterly Journal* (xi. 309). It consists of a black-lead earthenware tube, inclosing a bar of platinum immovably fixed to it at one end, which is closed, and terminating at its other extremity in a fine platinum wire, which passes round the axis of a toothed wheel playing into the teeth of another wheel, to which is attached an index traversing a circle divided into 360°. When the platinum bar is heated by putting the tube into a fire, its degree of expansion is exhibited by the index, the value of the degrees upon the circle, as compared with the mercurial thermometer, being ascertained by a method pointed out by Mr. Daniell in the construction of each particular instrument. The following points probably approach very near to accuracy :—

	Pyrom.		Therm.
Boiling of mercury	92	=	644
Fusing point of tin	63	=	441
———— bismuth	66	=	462
———— lead	87	=	609
———— zinc	94	=	648
———— brass	267	=	1869
———— silver	319	=	2233
———— copper	364	=	2548
———— gold	370	=	2590
———— cast iron	497	=	3479
Red heat just visible in day-light, about	140	=	980
Heat of a common parlour fire	163	=	1141

Air is sometimes resorted to as indicating very small changes of temperature; and of air thermometers, that described by Professor Leslie, (*Experimental Inquiry into the Nature and Propagation of Heat*, by John Leslie, London, 1804, p. 9, &c.) under the name of the *Differential Thermometer*, is the best. It consists of two large glass bulbs containing air, united by a tube twice bent at right angles, containing coloured sulphuric acid. When a hot body approaches one of the bulbs, it drives the fluid towards the other. The great advantage of this instrument in delicate experiments is, that general changes of the atmosphere's temperature do not affect it, but it only indicates the *difference* of temperature between the two balls.



Sometimes a simple form of the air thermometer is employed, consisting merely of a tube with a bulb at one extremity, the other end being open, and immersed into coloured water, which, by expelling a portion of air from the tube by heat, is made to stand at any convenient height: the liquid in the tube descends and rises on heating and cooling the air in the bulb.



The relative quantities of heat which different bodies in the same state require to raise them to the same thermometric temperature, is called their *specific heat*, and those bodies which require most heat are said to have the greatest *capacity* for heat. That the quantity of heat in different bodies of the same temperature is different, was first shown by Dr. Black, in his Lectures at Glasgow, in 1762. His proof consisted in mixing different substances together as described in the next paragraph. Dr. Crawford (on Animal Heat) and Dr. Irving (Chemical

Essays) experimented in the same way, but their results are too discordant to be entitled to confidence.

It has been stated as a proof of the accuracy of the thermometer, that equal volumes of the same fluid, at different temperatures, give the arithmetical mean, on mixture. Thus, the temperature of a pint of hot and a pint of cold water is, after mixture, as near as possible half-way between the extremes. The cold water being of a temperature of 50°, and the hot of 100°, the mixture raises the thermometer to 75°. But if a pint of quicksilver at 100° be mixed with a pint of water at 50°, the resulting temperature is not 75°, but 70°; so that the quicksilver has lost 30°, whereas the water has only gained 20°. Hence it appears, that the capacity of mercury for heat is less than that of water; and if the *weight* of the two bodies be compared, which are as 13.3 to 1, their capacities will be to each other as 19 to 1.

In cases where the specific heat of bodies is to be ascertained, it is convenient that water should be the standard of comparison, or = 1. The following is a general formula for determining the specific heat of bodies, from the temperature resulting from the mixture of two bodies at unequal temperatures, whatever be their respective quantities. Multiply the weight of the water by the difference between its original temperature, and that of the mixture; also, multiply the weight of the other liquid by the difference between its temperature, and that of the mixture: divide the first product by the second, and the quotient will express the specific heat of the other substance, that of water being = 1. Thus, 20 ounces of water at 105°, mixed with 12 ounces of spermaceti oil at 40°, produce a temperature of 90°. Therefore, multiply 20 by 15 (the difference between 105 and 90) = 300. And multiply 12 by 50 (the difference between 40 and 90) = 600. Then 300, ÷ 600, = $\frac{1}{2}$, which is the specific heat of oil: that is, water being = 1, oil is = 0.5.

The capacities of bodies for heat have considerable influence upon the rate at which they are heated and cooled. Those bodies which are most slowly heated and cooled have generally the greatest capacity for heat. Thus, if equal quantities of water and quicksilver be placed at equal distances from the fire, the quicksilver will be more rapidly heated than the water, and the metal will cool most rapidly when carried to a cold place. Upon this principle, Professor Leslie ingeniously determined the specific heat of bodies, observing their relative times of cooling a certain number of degrees, comparatively with water, under similar circumstances.

Lavoisier and La Place endeavoured to ascertain the specific heat of bodies by the relative quantities of ice which they were capable of thawing, during cooling; thus, if a pint of water in cooling from 212° to 32° melted a pound of ice, and a pint of oil in passing through the same range of temperature only gave out heat enough to thaw half a pound of ice, it was concluded that the specific heat of water being = 1, that of the oil was = 0.5. The instrument which they employed in these researches, and which is fully described in Lavoisier's *Elements of Chemistry*, is not, however, susceptible of accuracy, for Mr. Wedgewood has shown that it is scarcely possible to separate the water from the ice.—*Phil. Trans.*, vol. lxxiv.

MM. Petit and Dulong have published some important researches on the subject of specific heat, which render it probable that the atoms of all simple substances have exactly the same capacities for heat; hence the specific heat of an elementary substance, multiplied into the weight of its prime equivalent, should always give the same product (*Ann. de Ch. et Phys.*, vol. x.): the following Table shews their results:—

	Specific heats, that of water being 100.	Weight of the atoms, oxygen being 1.	Product of these two numbers.
Bismuth . . .	0.0288	13.300	0.3830
Lead . . .	0.0293	12.950	0.3794
Gold . . .	0.0298	12.430	0.3704
Platinum . .	0.0314	11.160	0.3740
Tin . . .	0.0514	7.350	0.3779
Silver . . .	0.0557	6.750	0.3759
Zinc . . .	0.0927	4,030	0.3736
Tellurium . .	0.0912	4.030	0.3675
Copper . . .	0.0949	3.957	0.3755
Nickel . . .	0.1035	3.690	0.3819
Iron . . .	0.1100	3.392	0.3731
Cobalt . . .	0.1498	2.460	0.3685
Sulphur . . .	0.1880	2.011	0.3780

They have also shown that the specific heats of bodies are greater at high than at low temperatures; the specific heat of iron, for instance, was found to be as follows:—

	Centigrade.	Specific Heat.
Iron	0 to 100°	0.1098
	0 to 200	0.1150
	0 to 300	0.1218
	0 to 350	0.1255

The same holds good in respect to other bodies, as shown in the following Table:—

	Specific Heats between 0 and 100 cent.	Specific Heats between 0 and 300 cent.
Mercury	0.0330	0.1350
Zinc	0.0927	0.1015
Antimony	0.0507	0.0549
Silver	0.0557	0.0611
Copper	0.0949	0.1013
Platinum	0.0355	0.0355
Glass	0.1770	0.1900

Perhaps the least exceptionable experiments to ascertain the specific heats of gaseous bodies, are those of Delaroche and Berard (*Ann. de Chim.* lxxxv., or *Ann. of Philos.* v. ii.); by an ingenious apparatus they determined the relative heating powers of the different substances: the following Tables shew their general results:—

	Equal volumes.	Equal weights.	Sp. gravity.
Air	1.0000	1.0000	1.0000
Hydrogen	0.9033	12.3401	0.0732
Carbonic acid	1.2583	0.8280	1.5196
Oxygen	0.9765	0.8848	1.1036
Nitrogen	1.0000	1.0318	0.9691
Nitrous Oxide	1.3503	0.8878	1.5209
Olefiant gas	1.5530	1.5763	0.9885
Carbonic oxide	1.0340	1.0304	0.9569

To reduce these numbers to the standard of water, three methods were employed; from which the numbers 0.2498, 0.2697, and 0.2813 were obtained for atmospheric air. They have taken 0.2669 as the mean, to which all the above results are referred, as follows :—

Water	1.0000
Air	0.2669
Hydrogen gas	3.2936
Carbonic acid	0.2210
Oxygen	0.2361
Nitrogen	0.2754
Nitrous oxide	0.2369
Olefiant gas	0.4207
Carbonic oxide	0.2884
Aqueous vapour	0.8470

Clement and Desormes (*Journal de Physique*, lxxxix.) consider the specific heat of air to water as 0.250 to 1.000, or exactly one-fourth. Their experiments, as well as those of Delaroche and Berard, shew that the specific heat of any one gas considered with respect to its volume, augments with its density, but in a proportion less than the increase of density ; the following are their results :—

	Inches Barom.	Specific Heat.
Atmospheric air	39.6	1.215
Ditto	29.84	1.000
Ditto	14.92	0.693
Ditto	7.44	0.540
Ditto	3.74	0.368
Nitrogen	29.84	1.000
Oxygen	29.84	1.000
Hydrogen	29.84	0.664
Carbonic Acid	29.84	1.500

The capacity of gases, therefore, and vapours differs with the nature of the gas, and with its density. In gases, dilatation produces cold, and compression excites heat. A thermometer suspended in the receiver of the air-pump sinks during exhaustion, and sudden compression of air produces heat sufficient to inflame tinder. In liquids, too, condensation diminishes capacity for heat ; hence the mixture of spirit and water, and of sulphuric acid and water, evolves heat. The increased capacity which air acquires by rarefaction has its influence in modifying natural temperatures. The air becoming rarer as it ascends, absorbs its own heat, and hence becomes cold in proportion as it recedes from the earth's surface; thus moisture, rain, or snow, are thrown down on the mountain-tops.

When different bodies are exposed to the same source of heat, they suffer it to pass through them with very different degrees of velocity, or they have various *conducting powers* in regard to heat. Among solid bodies, metals are the best conductors; and silver, gold, and copper, are better conductors than platinum, iron, and lead. Next to the metals, we may, perhaps, place the diamond, and topaz; then glass; then siliceous and hard stony bodies in general; then soft and porous earthy bodies, and wood; and lastly, down, feathers, wool, and other porous articles of clothing.

To compare the relative conducting powers of metals, and some other solids, small cones of the different substances may be used, about three inches high, and half an inch in diameter at their bases: these may be tipped at the apex with a small piece of wax, and being placed on a heated metallic plate, will indicate the conducting powers by the relative times required to fuse the wax, which will be directly as the power of conducting heat. Ingenhouz* in similar experiments employed small rods of the same form and length: he found silver the best conductor; then gold; then tin and copper; then iron, platinum, and lead. More lately M. Despretz† has published some observations on the conducting powers of several substances, from which he concludes that platinum is a better conductor of heat than silver, but that this is not the case is proved by holding similar bars or wires of those metals in the flame of a candle, when the fingers will soon be burned by the silver bar, but the heat will be a much longer time in pervading that of platinum.

The difference between the conducting power of the diamond and rock crystal or glass, is shown by applying the tongue to those substances, when the former feels colder than the latter.

From the experiments of Professor Mayer, of Erlangen, (*Annales de Chimie*, tom. xxx.) it would appear that the conducting powers of different woods is in some measure inversely

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* Journal de Physique, 1789, p. 68.

† Ann. de Chimie et Physique, xxxvi. 422.

as their specific gravities, as shown by the following table, water being assumed as = 1.

	Conducting Power.	Specif. Grav.
Water	10	1.000
Ebony wood	21.7	1.054
Apple tree	27.4	0.639
Ash	30.8	0.631
Beech	32.1	0.692
Hornbeam	32.3	0.690
Plum tree	32.5	0.687
Elm	32.5	0.646
Oak	32.6	0.668
Pear tree	33.2	0.603
Birch	34.1	0.608
Silver fir	37.5	0.495
Alder	38.4	0.484
Scotch fir	38.6	0.408
Norway Spruce	38.9	0.447
Lime	39.0	0.408

Count Rumford's experiments on the conducting power of several substances used as clothing offer some interesting results. (*Phil. Trans.* 1792.) He found that a thermometer enclosed in a tube and bulb of the same shape, but large enough to allow of an inch vacant space between the two, being previously heated, required 576 seconds to cool 135°. When 16 grains of lint were diffused through the confined air, it took 1032 seconds to undergo the same change of temperature; and 1305 seconds with the same weight of Eider-down. The compression of flocculent substances to a certain extent, renders them still inferior conductors: thus, when the space which in the above experiments contained 16 grains of Eider-down, was filled with 32, and then with 64 grains, the times required for the escape of 60 degrees of heat were successively increased from 1305″ to 1472″ and 1615″.

On the other hand, to show the effect of mere *texture*, similar comparative trials were made of the conducting powers of equal weights of raw silk, of ravelings of white taffeta, and of common sewing silk, of which the first has the finest fibre, the second less fine, and the third from being twisted and harder is much coarser. The difference between these three modifications of the same substance is very striking, the raw silk detaining the heat for 1284″, the taffeta ravelings 1169″, and the silk thread only 917″.—Aikin's *Dict.*, Art. Caloric.

Liquids and gases are very imperfect conductors of heat, and heat is generally distributed through them by a change of specific gravity, as before stated.

If we apply heat to the upper surface of any fluid, it will with great difficulty make its way downwards. Count Rumford considered fluids as non-conductors of heat; but the more accurate researches of Dalton, Hope, Murray, (*System of Chemistry*, vol. i.,) and Thomson, (*System of Chemistry*, vol. i.,) have demonstrated that they do conduct, though very imperfectly.

Thus, if we carefully pour hot oil upon water in a tall glass jar with delicate thermometers placed at different distances under the surface, it will be found that those near the heated surface indicate increase of temperature: it might here be said that the heat was conducted by the sides of the jar, and so communicated to the water; to obviate such objection, Mr. Murray made the experiment in a vessel of ice, which being converted into water at 32°, cannot convey any degree of heat above 32° downwards; yet the thermometers were affected, as in the former trial.

Experiments on the conducting power of air are complex and difficult, and the results hitherto obtained are unsatisfactory. They are interfered with by several circumstances hereafter to be noticed, and especially by radiation, but it has been sufficiently shown that air is a very bad conductor of heat; worse, probably, than liquids.

The different conducting powers of bodies in respect to heat, are shown in the application of wooden handles to metallic vessels; or a stratum of ivory or wood is interposed between the hot vessel and the metal handle. The transfer of heat is thus prevented. Heat is confined by bad conductors; hence clothing for cold climates consists of woollen materials; hence, too, the walls of furnaces are composed of clay and sand. Confined air is a very bad conductor of heat; hence the advantage of double doors to furnaces, to prevent the escape of heat; and of a double wall, with an interposed stratum of air, to an icehouse, which prevents the influx of heat from without.

From the different conducting powers of bodies in respect to heat, arise the sensations of heat and cold experienced upon their application to our organs, though their thermometric temperature is similar. Good conductors occasion, when touched, a greater sensation of heat and cold than bad ones. Metal feels cold because it readily carries off the heat of the body; and we cannot touch a piece of metal immersed in air of a temperature moderate to our sense.

Heat has great influence on the *forms* or *states* of bodies. When we heat a solid, it becomes fluid or gaseous; and liquids are converted into aëriform bodies or vapours. Dr. Black investigated this effect of heat with singular felicity, and his researches rank among the most admirable efforts of experimental philosophy. (Black's *Lectures*, edited by John Robison, LL.D.) During the liquefaction of bodies, a quantity of heat is absorbed, which is essential to the state of fluidity, and which does not increase the sensible or thermometic temperature. Consequently, if a cold solid body, and the same body hot and in a liquid state, be mixed in known proportions, the temperature after mixture will not be the proportional mean, as would be the case if both were liquid, but will fall short of it; much of the heat of the hotter body being consumed in rendering the colder solid *liquid*, before it produces any effect upon its *sensible temperature*.

Equal parts of *water* at 32°, and of *water* at 212° will produce on mixture a mean temperature of 122°. But equal parts of *ice* at 32°, and of water at 212°, will only produce (after the liquefaction of the ice) a temperature of 52°, the greater portion of the heat of the water being employed in thawing the ice, before it can produce any rise of temperature in the mixture. To heat thus *insensible* or *combined*, Dr. Black applied the term *latent heat*. The actual loss of the thermometric heat in these cases was thus estimated: a pound of ice at 32° was put into a pound of water at 172°; the ice melted, and the temperature of the mixture was 32°. Here the water was cooled 140°, while the *temperature* of ice was unaltered; that is, 140° of heat disappeared, their effect being not to increase temperature, but to produce fluidity.

The same phenomena are observable in all cases of liquefaction, and we produce artificial cold, often of great intensity, by the rapid solution of certain saline bodies in water. Upon this principle the action of freezing mixtures depends, some of which may frequently be conveniently and economically applied to the purpose of cooling wine or water in hot climates, or where ice cannot be procured. The following table shows the results of some of Mr. Walker's experiments on this subject.

Mixtures.	Parts.	Thermometer sinks
Muriate of ammonia Nitre Water	5 5 16	From 50° to 10°
Nitrate of ammonia Water	1 1	From 50° to 4°
Sulphate of soda Diluted sulphuric acid	5 4	From 50° to 3°
Snow Common salt	1 1	From 32° to 0°
Muriate of lime Snow	3 2	From 32° to – 50°
Snow Diluted sulphuric acid Diluted nitric acid	2 1 1	From – 10° to—56°
Snow or pounded ice Common salt Nitrate of ammonia	12 5 5	From 18° to – 25°
Muriate of lime Snow	3 1	From — 40° to – 73°
Diluted sulphuric acid Snow	10 8	From – 68° to – 91°

To produce these effects, the salts employed must be fresh crystallized, and newly reduced to a very fine powder. The vessels in which the freezing mixture is made should be very thin, and just large enough to hold it, and the materials should be mixed together as quickly as possible.

In order to produce great cold, they ought to be first reduced to the temperature marked in the table, by placing them in some of the other freezing mixtures; and then they are to be mixed together in a similar freezing mixture.—*Phil. Trans.* 1795.

When fluids are converted into solids, their latent heat becomes sensible; thus when a solution of Glauber's salt is made *suddenly* to crystallize, its temperature is considerably augmented. Its slow crystallization may be shown to be attended by the same effect. Thus, if we dissolve one part of the salt in five of water, and immerse the vessel containing the solution into a freezing mixture, it gradually cools down to 31°. At this temperature the salt begins to be deposited, and entirely prevents the further cooling. When water is poured upon quicklime, a great degree of heat is produced by the solidification which it suffers in consequence of chemical combination. Congelation, therefore, is to surrounding bodies a heating process, and liquefaction a cooling process. The following is a table of the congealing points of a variety of bodies drawn up by Dr. Ure.

Sulphuric ether			—	46°
Liquid ammonia			—	46
Nitric acid, spec. grav.	1.424		—	45.5
Sulphuric acid, spec. grav.	1.6415		—	45
Mercury			—	39
Nitric acid, spec. grav.	1.407		—	30.1
Sulphuric acid	1.8064		—	26
Nitric acid	1.3880		—	18.1
Ditto	1.2583		—	17.7
Ditto	1.3290		—	2.4
Brandy			—	7.0
Sulphuric acid	1.8376		+	1.
Pure prussic acid				4 to 5
Common salt	25 +	water 75		4
Ditto	22.2 +	„ 77.8		7.2
Sal ammoniac	20 +	„ 80		8.
Common salt	20 +	„ 80		9.5
Ditto	16.1 +	„ 83.9		13.5
Oil of turpentine				14.
Strong wines				20
Rochelle salt	50 +	water 50		21.
Common salt	10 +	„ 90		21.5
Oil of bergamot				23
Blood				25
Common salt	6.25 ×	water 93.75		25.5
Epsom salts	41.6 +	„ 58.4		25.5
Nitre	12.5 +	„ 87.5		26.
Common salt	4.16 +	„ 95.84		27.5
Copperas	41.6 +	„ 58.4	+	28
Vinegar				28
Sulphate of zinc.	53.3 +	water 46.7		28.6
Milk				30
Water				32
Olive oil				36

Sulphur and phosphorus, equal parts	40°
Sulphuric acid, spec. grav. 1.741	42
Ditto ,, 1.780	46
Oil of anise	50
Concentrated acetic acid	50
Tallow, Dr. Thomson	92
Phosphorus	108
Stearin from hog's lard	109
Spermaceti	112
Tallow, Nicholson	127
Margaric acid	134
Potassium	136.4
Yellow wax	142
Ditto	149
White wax	155
Sodium	194
Sulphur, Dr. Thomson	218
Ditto Dr. Hope	234
Tin	442
Bismuth	476
Lead	612
Zinc, by Sir H. Davy	680
Ditto, Brogniart	698
Antimony	809 ?

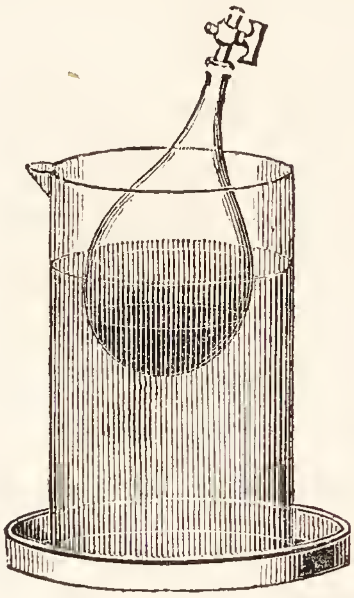
The solidifying temperature of the bodies above tallow, in the table, is usually called their freezing or congealing point; and of tallow and the bodies below it, the fusing or melting point.

When liquids are heated, they acquire the gaseous form, and become invisible elastic fluids, possessed of the mechanical properties of common air. Steam, for instance, when perfectly formed, is quite invisible, as may be shown by boiling water in a flask, when perfect transparency will exist in the upper part of the vessel. It is only when it begins to be condensed that steam becomes visible. The same fact is shown by the fogs which are produced by the mixture of warm and cold moist air, or by a sudden change from warm to cold weather, the vapour, invisible at the higher temperature, being rendered visible in consequence of partial condensation by cold. Liquids retain the elastic state as long as their temperature remains sufficiently high, but re-assume the liquid form when cooled again. Different fluids pass into the aëriform state at different temperatures, or their boiling points are different; these are also regulated by the density of the atmosphere. If we diminish atmospheric pressure, we lower the boiling point. When the barometer is at 28 inches, water will boil at a lower temperature than when it is at 31 inches. Water under mean atmospheric pressure of 30 inches of mercury, boils in a metallic vessel at 212°. When the barometer falls to 29 inches, the boiling point of water is lowered to 210.08°; when it rises to 31 inches, the boiling point is elevated to 213.92; one degree of Fahrenheit corresponding, according to Mr. Wollaston, to a difference of 0.589 inches of barometric pressure. At the top of Mont Blanc, Saussure found that it boiled at 187°, so that the heights of mountains, and even of buildings, may be calculated by reference to the temperature at which water boils upon their summits. The Rev. Mr. Wollaston has described to the Royal Society the method of constructing a thermometer of extreme delicacy, applicable to these purposes.—*Phil. Trans.* 1817. In the vacuum of an air-pump, fluids boil at temperatures considerably below their ordinary boiling points.

Gay Lussac has shown that the temperatures at which liquids boil is modified by the nature of the vessel employed, (*Ann. de Chim. et Phys.*, vii. 307. *Quarterly Journal of Science*, v. 361.) Under mean pressure, water boils in a metallic vessel at 212°; in a glass flask it often rises to 214° or 216°; and where the steam is irregularly formed, occasioning a bumping in the vessel, the boiling point is proportionately high and irregular, but, upon throwing in a few metallic filings, pieces of wire, or other finely-divided and insoluble materials, the generation of steam is facilitated, and the boiling point falls to its standard. Dr. Bostock has observed an analogous effect in ether and alcohol (*Ann. of Phil. N. S.* ix. 196). Ether, heated in a glass vessel, had its boiling point lowered nearly 50°, by introducing a few shavings of cedar; and alcohol of the specific gravity of .849 had its boiling point reduced in the same way between 30° and 40°.

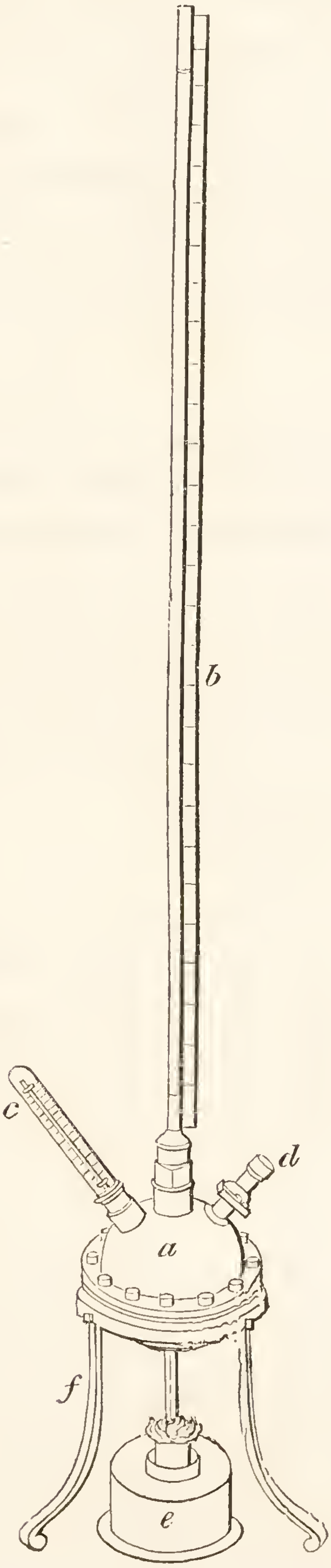
The following apparently paradoxical experiment illustrates the influence of diminished pressure in facilitating ebullition. Insert a stopcock securely into the neck of a Florence flask, containing a little water, and heat it over a lamp till the water boils, and the steam freely escapes by the open stopcock; then suddenly remove the lamp and close the cock.

The water will soon cease to boil; but if plunged into a vessel of cold water, ebullition instantly recommences, but ceases if the flask be held near the fire: the vacuum in this case being produced by the condensation of the steam.



In the arts it is often a matter of importance to evaporate liquids rapidly, and, at the same time, at the lowest possible temperature. Upon the principle just explained, Mr. Howard contrived an apparatus for boiling sugar in vacuo, by which the danger of injuring the syrup by excess of heat was prevented; and Mr. Barry has described an ingenious apparatus applicable to similar purposes, and especially to distillation and other operations of the Pharmaceutical Laboratory.—(*Med. Chir. Trans.* vol. x.)

Under increased pressure, on the contrary, fluids require a higher temperature to produce their ebullition, as may be shown by the following experiments: *a* is a strong brass globe, composed of two hemispheres screwed together with flanches; a portion of quicksilver is introduced into it, and it is then about half filled with water. *b* is a barometer-tube passing through a steam-tight collar, and dipping into the quicksilver at the bottom of the globe. *c* is a thermometer graduated to about 400°, and also passing through an air-tight collar. *d* is a stopcock, and *e* a large spirit lamp. The whole is supported upon the brass frame and stand *f*. Upon applying heat to this vessel, the stopcock being closed as soon as the water boils, it will be found that the temperature of the water and its vapour increases with the pressure, which is measured by the ascent of the mercury in the barometer-tube. The thermometer, under an atmospheric pressure of 30 inches, being at 212°, will be elevated to 221.6° under an additional pressure



of 5 inches of mercury, and to 269.6° under an additional pressure of 30 inches, or one additional atmosphere or thereabouts; each inch of mercury, above 30, producing by its pressure a rise of about 1.92° in the thermometer. The barometer-tube also serves the purpose of a safety-valve, the strength of the brass globe being such as to resist a greater pressure than that of one atmosphere.

The temperature of steam is always that of the liquid producing it, hence the high temperature of steam generated under pressure; and as this elevation of temperature may be accurately regulated by the degree of pressure, high-pressure steam is often conveniently applied as a source of steady heat.

The following is a tabular view of the boiling points by Fahrenheit's scale of several liquids, under a mean barometrical pressure of thirty inches. (Ure's *Dictionary*, Art. CALORIC.)

		Boiling point.
Ether, spec. grav. 0.7365 at 48°.	G. Lussac	100°
Carburet of sulphur	„	113
Alcohol, spec. grav. 0.813	Ure	173.5
Nitric acid 1.500	Dalton	210
Water		212
Saturated sol. of Glauber's salt	Biot	$213\frac{1}{3}$
„ sugar of lead	„	$215\frac{2}{3}$
„ sea salt	„	$224\frac{1}{3}$
Muriate of lime 2 + water 1	Ure	230
„ 35.5 + „ 64.5	„	235
„ 40.5 + „ 59.5	„	240
Muriatic acid, 1.094	Dalton	232
„ 1.127	„	222
„ 1.047	„	222
Nitric acid, 1.45	„	240
„ 1.42	„	248
„ 1.40	„	247
„ 1.35	„	242
„ 1.30	„	236
„ 1.16	„	220
Rectified petroleum	Ure	306
Oil of turpentine	„	316
Sulphuric acid, spec. grav. 1.30 +	Dalton	240
„ „ 1.408	„	260
„ „ 1.520	„	290
„ „ 1.650	„	350
„ „ 1.670	„	360
„ „ 1.699	„	374
„ „ 1.730	„	391
„ „ 1.780	„	435

			Boiling point.
Sulphuric acid, spec. grav.	1.810	Dalton	473
" "	1.819	"	487
" "	1.827	"	501
" "	1.833	"	515
" "	1.842	"	545
" "	1.847	"	575
" "	1.848	"	590
" "	1.849	"	605
" "	1.850	"	620
" "	1.848	Ure	600
Phosphorus			554
Sulphur			570
Linseed oil			640 ?
Mercury, (Dulong, 662°)			656

The boiling points of various saline solutions is partly dependent upon the quantity and partly upon the nature of the salt dissolved, and the steam arising from them has the same temperature as that of the boiling solution. (Faraday and Gay Lussac, *Ann. of Phil. N. S.* v. 75.) Mr. T. Griffiths has determined the boiling points of a number of saturated solutions of salts, of which a table is given in the *Quarterly Journal* (xviii. 90.) The following are a few of the results :—

Name of salt.	Dry salt in 100 of solution.	Boiling point.
Acetate of soda	60	256°
Nitrate of soda	60	246
Nitrate of potassa	74	238
Muriate of ammonia	50	236
Muriate of soda	30	224
Sulphate of magnesia	57	222
Alum	52	220
Sulphate of copper	45	216
Sulphate of iron	54	216
Acetate of lead	41	215
Sulphate of soda	31	213

The conversion of a liquid into vapour is always attended with great loss of thermometric heat ; and as liquids may be regarded as compounds of solids and heat, so vapours may be considered as consisting of a similar combination of heat with liquids ; in other words, a great quantity of heat becomes latent during the formation of vapour. This is easily illustrated by immersing a thermometer into an open vessel of water placed over a lamp. The quicksilver rises to 212°, the water then boils, and although the source of heat remains, neither the water nor the steam acquire a higher temperature than 212°; the heat then becomes latent, and is consumed in the formation of steam. When water, as in the preceding experiment with the brass globe, is heated above the boiling point, and the cock suddenly opened, a quantity of steam rushes out with great violence, and the remaining water immediately falls to 212°. The quantity of water constituting the lost steam is very small, yet it has carried off the whole excess of heat from that in the globe.

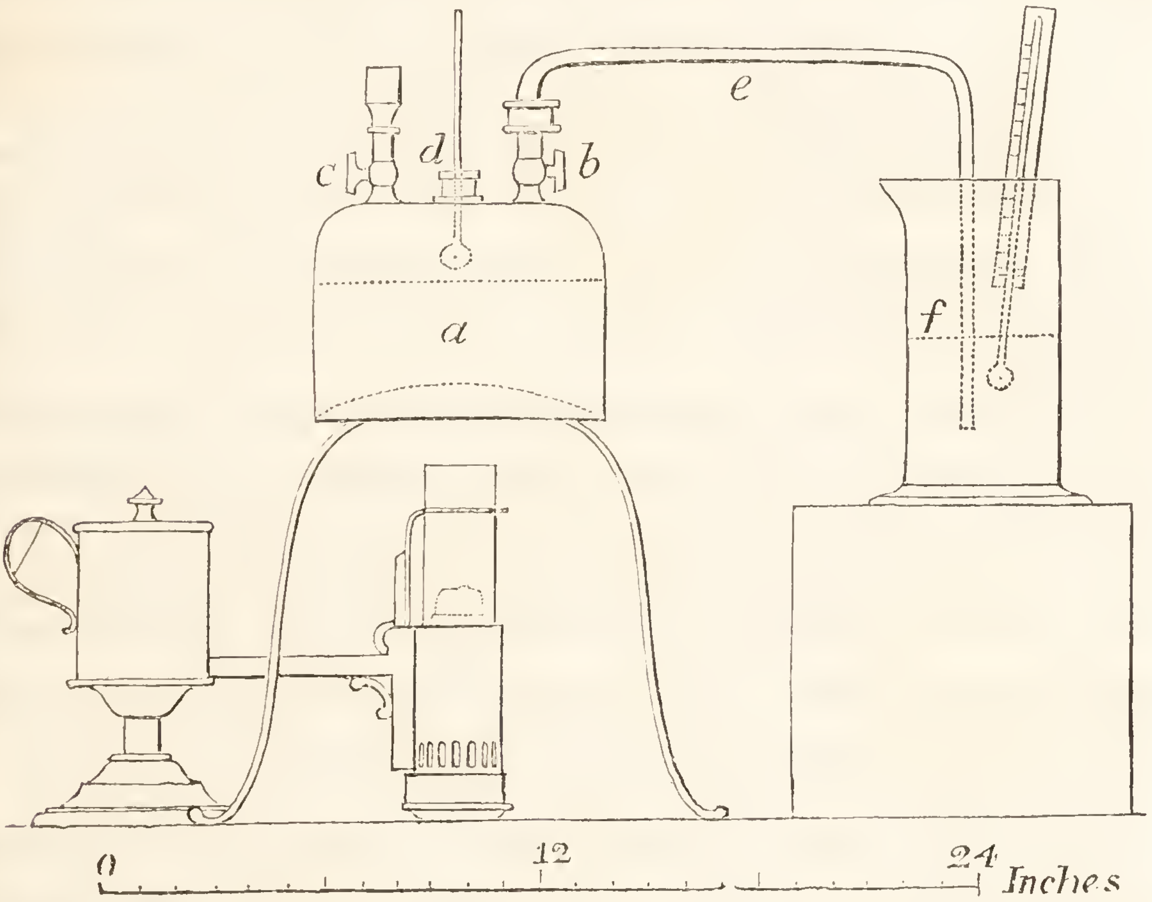
To ascertain the absolute loss of thermometric heat in these cases, Dr. Black instituted the following experiments: he noted the time required to raise a certain quantity of water to its boiling point; he then kept up the same heat till the water was evaporated, and marked the time consumed by the process; it was thus computed to what height the temperature would have risen, supposing the rise to have gone on above 212°, in the same ratio as below it; and as the temperature of the steam was the same as that of the water, it was fairly inferred that all the heat above 212° was essential to the constitution of aqueous vapour. Dr. Black estimated this quantity at about 810°; that is, the same quantity of heat which is required for the total evaporation of boiling water at 212° would be sufficient to raise the water 810° above its boiling point, or to 1022° had it continued in the liquid state. There are other means of ascertaining the latent heat of steam, which lead us to place it between 900° and 1000°.

The following table of the latent heat of steam and some other vapours is extracted from a paper in the *Philosophical Transactions for* 1818, by Dr. Ure.

		Corrected column.
Vapour of water at 212°	967° .00	1000
,, alcohol	442 .00	457
,, ether	302 .38	312.9
,, petroleum	177 .87	183.8
,, oil of turpentine	177 .87	183.8
,, nitric acid	531 .99	550.
,, liquid ammonia	837 .28	865.9
,, vinegar	875 .00	903.

When steam is again condensed, or when vapours re-assume the liquid state, their latent heat becomes sensible; and in this way it is obvious that a small quantity of steam will, during its condensation, communicate heat sufficient to boil a large quantity of water.

The small boiler, represented in the annexed cut taken from Dr. Henry's *Elements of Chemistry*, may be conveniently employed in experiments on the latent heat of steam.



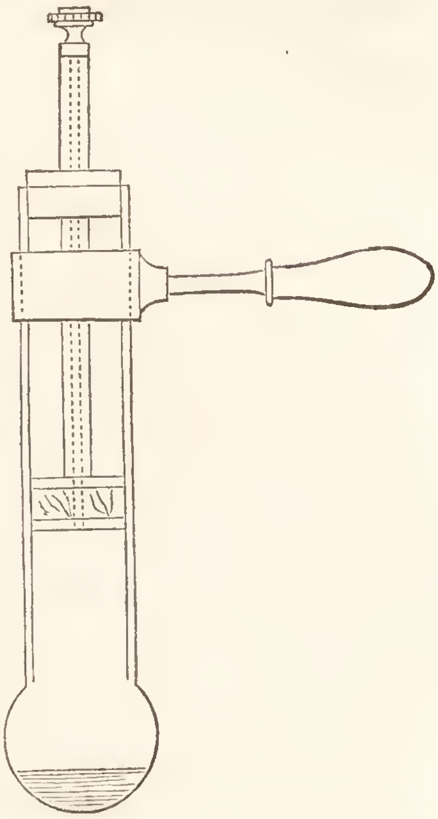
For this purpose the tube *e* must be screwed on the stop-cock *b*, and immersed into the glass of water *f*. The cock *c* being closed, the steam arising from the boiling water *a* will pass into the cold water *f*, the temperature of which will be much augmented by its condensation. Ascertain the increase of temperature and weight, and the result will show how much a given weight of water has had its temperature raised by a certain weight of condensed steam. To another quantity of water, of the same weight and temperature as that in the jar at the outset of the experiment, add a quantity of water at 212°, equal in weight to the condensed steam; it will be found, on comparing the resulting temperatures, that a given weight of steam has produced, by its condensation, a much greater elevation of temperature than the same quantity of boiling water. (*Henry*, vol. i. p. 106, seventh edit.) If, for instance, 100 gallons of water at 50° be mixed with 1 gallon at 212°, the temperature of the whole will be raised by about 1½°. But if a gallon of water be condensed from the state of steam in a still tub containing 100 gallons of water, the water will in that case be raised 11°. A gallon of water, therefore, condensed from steam raises the temperature of 100 gallons of cold water 9½° more than a gallon of boiling water. If the heat imparted to 100 gallons of water by 8 pounds of steam could be condensed in 1 gallon of water, it would raise it to 950°; and a gallon of water converted into steam of ordinary density contains as much heat as would bring 5½ gallons of ice-cold water to the boiling point. The quantity of ice which is melted by steam of mean density is invariably 7½ times the weight of the steam. (Henry's *Elements*—Black's *Lectures*.)

In breweries and other manufactories, where large quantities of warm and boiling water are consumed, it is frequently heated by conveying steam into it, or by suffering steam-pipes to traverse the vessels, or by employing double vessels, a plan adopted with particular advantage in the laboratories at Apothecaries' Hall. This method of warming water has also been very advantageously applied to heating baths. Where a higher temperature than 212° is required, it is necessary to employ steam under adequate pressure, and a very ingenious means of producing high-pressure steam for this purpose has been contrived by Messrs. J. and P. Taylor, and applied by them, upon a very large scale, at Whitbread and Co.'s brewhouse. The heat given off by steam during its condensation, is also often advantageously applied to warming buildings, and is at once safe, salubrious, and economical.

The enormous increase of bulk which water suffers in conversion into steam is well known. According to Watt, a cubic foot of water furnishes 1800 cubic feet of steam at 212°, and under a pressure of 30 inches barometer; but according to Gay Lussac, the bulk of steam is only 1698 times that of water. (See *Water*.)

In the steam-engine, the elasticity of the vapour of water is most importantly employed as a moving power. Its action may be said to depend upon two properties of steam, namely, the expansive force communicated to it by heat, and its ready condensation into water by cold. These properties are well shown by a little apparatus contrived by

Dr. Wollaston, and shown in the annexed sketch. It consists of a cylindrical glass tube, 6 inches long and $\frac{3}{4}$ of an inch diameter, and blown out a little at the lower end; it is held in a brass ring, to which a wooden handle is attached, and contains a piston, which, as well as its rod, is perforated, and may be opened or closed by the screw at top: it is kept central by passing through a slice of cork. When used, a little water is put into the bulb and heated over a spirit lamp: the aperture in the piston-rod being open, the air is thus expelled, and when steam freely follows it, the screw may be closed, when, on applying cold to the bulb, as, for instance, putting it upon the surface of a little mercury in a glass, the included steam is condensed and a vacuum formed, which causes the descent of the piston by the air's pressure. On again holding the bulb over the lamp, steam is reproduced, and the piston forced up. These alternate motions may be repeated upon the alternate applications of heat and cold. The moving power of the steam-engine is illustrated by this apparatus; but in that machine, as now constructed, the steam, instead of being cooled in the cylinder, is condensed in a separate vessel always immersed in cold water, and called the *condenser*, so that the temperature of the main cylinder is always kept up to 212°.

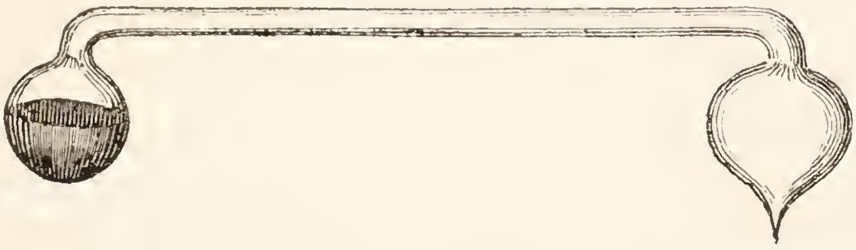


It has sometimes been stated that the density of vapours is in the direct ratio of the volatility of the liquids which produce them. Thus water boils at 212°, and the density of its vapour (air being = 1000) is 623. Alcohol boils at 176°, and is converted into 659 times its bulk of vapour (at 212°), the density of which is = 1.600. Sulphuric ether boils at 98, and affords 443 times its volume of vapour of a density = 2.570. But Gay Lussac has shown that sulphuret of carbon, which boils at a higher temperature than ether, namely, at 110°, yields a heavier vapour, its density being 2.637.

The existence of vapours of great density under high pressures and temperatures has been shown by the experiments of M. Cagniard de la Tour. (*Ann. de Ch. et Phys.*, xxi. 127—178; *Quarterly Journal*, xv. 145.) Although pressure restrains the volatilisation of a liquid, it occurred to him that there should be a limit beyond which liquids would notwithstanding be converted into vapour, provided sufficient space be allowed for its generation. A strong glass tube, two-fifths filled with alcohol, and hermetically sealed, was slowly and carefully heated: as the fluid dilated, its mobility increased, and when its volume was nearly doubled, it suddenly disappeared, and became a transparent vapour. The same results were obtained with naphtha and ether; the latter requiring less space than the former to be converted into vapour without breaking the tube, and naphtha less space than alcohol. The presence of atmospheric air in the tubes did not interfere with the results. The same experiment succeeded, though difficultly, with water, the tube containing only about one-fourth its volume. M. Cagniard de la Tour ascertained, by means of a mercurial gauge, the pressures of the above vapours. Alcohol, occupying in vapour a space little more than thrice its liquid volume, exerted a pressure = 119 atmospheres, and required for its production a temperature = 405 F. Ether, under the same circumstances, exerted a pressure of 38 atmospheres at 320 F. The temperature of the vapour of water was nearly that of melting zinc.

The cold produced by evaporation is, under certain circumstances, very great. Spirit of wine, and ether, which readily evaporate, produce considerable cold during that process, as may be shown by moistening the bulb of a thermometer with those liquids, and suffering them to evaporate spontaneously (See *Sulphuric Ether*). Upon this principle wine-coolers, and similar porous vessels, refrigerate the fluids they contain; and thus, by accelerating the evaporation of water, by exposing it under an exhausted receiver, containing bodies that quickly absorb its vapour, Professor Leslie has contrived to effect its congelation; the heat required for the conversion of one portion of the water into vapour being taken from the other portion, which is thus reduced to ice.—See *Supplement to Encyclopædia Brit.*, Art. Cold.

The instrument invented by Dr. Wollaston, and called by him the *Cryophorus*, acts upon a similar principle. It consists of a glass tube with a bulb at each extremity, of the shape annexed.



One of the bulbs is about half filled with water, and a good vacuum is produced in the other by boiling the water and sealing the tube whilst full of steam. On immersing the empty bulb in a freezing mixture, the water soon congeals in the other, although the intervening tube be two or three feet long. The vapour in the empty bulb is condensed by the cold, and a fresh quantity of vapour arises successively from the water in the other, by which so much heat is carried off as to cause it to congeal.—*Phil. Trans.* 1813.

In many natural operations the conversion of water into vapour, and the condensation of vapour in the form of dew and rain, is a process of the utmost importance, and tends considerably to the equalization of temperature over the globe: for the theory of the process is the same where evaporation is slow and spontaneous from surfaces exposed to air, as where they are rapidly boiling out of atmospheric contact, the formation of vapour being independent of any attraction or affinity of air for water.—(See *Meteorological Essays, &c.*, by J. F. Daniell, F.R.S.) Mr. Dalton has shown that the actual quantity of vapour which can exist in any given space entirely depends upon temperature. Thus, if some water be put into a dry flask, at 32°, very little vapour will be formed; it will contain more at 50°, and yet more at 70°. But if, being at 70°, the temperature be lowered to 32°, vapour will be condensed, and the portion retained will not exceed that originally taken up at 32°. The actual result of these experiments is the same when the flask is empty as when it contains air, but in the former case the evaporation is most rapid, for the air affords some mechanical resistance to the distribution of the vapour.—(*Hygroscopes and Hygrometers*.—See *Atmospheric Air*.)

In common chemical language, the term *Vapour* is applied to all those elastic fluids which are only permanent at high temperatures, or which are easily reducible to the solid or liquid state, while the term *Gas* is usually limited to such as are permanently elastic under all ordinary circumstances of temperature and pressure. Mr. Faraday's researches have, however, shown us that these terms are applicable under certain limitations only, for he has proved that many of the gases are merely the vapours of extremely volatile liquids, the boiling points of which, under common atmospheric pressure, are in many instances lower than any natural temperatures. Under great pressure these gases may be coerced into the liquid state, and, upon its removal, they instantly reassume the gaseous form, some with explosion, and some with the appearance of brisk ebullition, and the production of intense cold.

Mr. Faraday condensed the gases by exposing them to the pressure of their own atmospheres. He put the materials for producing them into a strong glass tube, a little bent in the middle, and hermetically sealed. When necessary, heat was applied, and when the pressure within became sufficient, the liquid made its appearance in the empty end of the tube, which was artificially cooled to assist in the condensation. In these experiments much danger is incurred from the bursting of the tubes: so that the operator should protect his face by a mask, and his hands by thick gloves. He succeeded in liquefying the following gases, which, as will be seen, require various degrees of pressure for the purpose.

	Pressure in Atmospheres.		Fahr.
Sulphurous acid	2	at	45°
Chlorine	4	„	60
Cyanogen	4	„	60
Ammonia	6.5	„	50
Sulphuretted hydrogen	17	„	50
Carbonic acid	36	„	32
Muriatic acid	40	„	50
Nitrous oxide	50	„	45

Nothing is known of the nature or cause of heat. It has been by some considered as a peculiar fluid, to which the term *Caloric* has been applied; and many phenomena are in favour of the existence of such a fluid. By others, the phenomena above described have been referred to a *vibratory motion* of the particles of matter, varying in velocity with the perceived intensity of the heat. In fluids and gases the particles are conceived to have a motion round their own axes. *Temperature*, therefore, would increase with the velocity of the vibrations; and increase of *capacity* would be produced by the motion being performed in greater space. The loss of temperature, during the change of solids into liquids and gases, would depend upon loss of *vibratory* motion, in consequence of the acquired *rotatory* motion.

Upon the other hypothesis, *temperature* is referred to the *quantity of caloric* present; and the loss of temperature, which happens when bodies change their state, depends upon the chemical combination of the caloric with the solid in the case of liquefaction, and with the liquid in the case of conversion into the aëriform state.

Section IV. Electricity.

If a piece of sealing-wax and of dry warm flannel be rubbed against each other, they both become capable of attracting and repelling light bodies. A dry and warm sheet of writing-paper rubbed with India rubber, or a tube of glass rubbed upon silk, exhibit the same phenomena. In these cases the bodies are said to be *electrically excited;* and when in a dark room, they always appear luminous.

If two pith-balls be electrified by touching them with the sealing-wax or with the flannel, they *repel* each other; but if one pith-ball be electrified by the wax, and the other by the flannel, they *attract* each other. The same applies to the glass and silk: it shows a difference in the electricities of the different bodies, and the experiment leads to the important conclusion, that *bodies similarly electrified repel each other, but that when dissimilarly electrified they attract each other.*

The term *electrical repulsion* is here used merely to denote the appearance of the phenomenon, the separation being probably referable to the new attractive power which they acquire, when electrified, for the air and other unelectrified surrounding bodies.

If one ball be electrified by sealing-wax rubbed by flannel, and another by silk rubbed with glass, those balls will *repel* each other; which proves that the electricity of the silk is the *same* as that of the sealing-wax. But if one ball be electrified by the sealing-wax and the other by the glass, they then *attract* each other, showing that they are *oppositely* electrified.

These experiments are most conveniently performed with a large downy feather suspended by a dry thread of white silk. If an excited glass tube be brought near it, it will receive and retain its electricity; it will be first attracted, and then repelled; and upon re-exciting the tube, and again approaching it, it will not again be attracted, but retain its state of repulsion; but upon approaching it with excited sealing-wax, it will instantly be attracted, and remain in contact with the wax till it has acquired its electricity, when it will be repelled, and in that state of repulsion it will be attracted by the glass. In these experiments care must be taken that the feather remains freely suspended in the air, and touches nothing capable of carrying off its electricity.

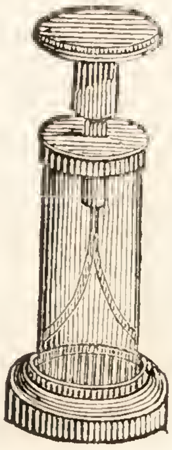
The terms *vitreous* and *resinous* electricity were applied to these two phenomena; but Franklin, observing that the same electricity was not inherent in the same body, but that glass sometimes exhibited the same phenomena as wax, and *vice versâ*, adopted another term, and, instead of regarding the phenomena as dependent upon two electric fluids, referred them to the presence of one fluid, in excess in some cases, and in deficiency in others. To represent these states he used the terms *plus* and *minus*, *positive* and *negative*. When glass is rubbed with silk, a portion of electricity leaves the silk and enters the glass; it becomes *positive*, therefore, and the silk *negative:* but when sealing-wax is rubbed with flannel, the wax loses and the flannel gains; the former, therefore, is negative, and the latter positive. All bodies in nature are thus regarded as containing the electric fluid, and when its equilibrium is disturbed, they exhibit the phenomena just described.

The substances enumerated in the following Table become positively electrified when rubbed with those which follow them in the list, but with those which precede them they become negatively electrical.—Biot, *Traité de Physique*, tom. ii. p. 220.

Cat's skin
Polished glass
Woollen cloth
Feathers
Paper
Silk
Gum lac
Rough glass.

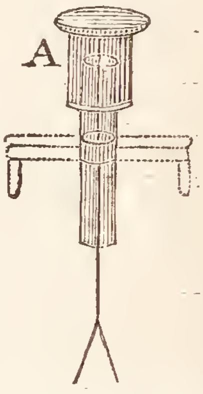
Though we speak of the negative power of sulphur, sealing-wax, amber, and resin, when rubbed with flannel, and of the positive power of polished glass rubbed by silk, of flannel rubbed by sealing-wax, of cat's skin rubbed by the hand, &c., it is by no means to be assumed that these negative and positive electrical states are peculiar to or always inherent in those particular bodies, but that they are merely produced by those particular modes of excitation; for, by other methods, glass may be rendered negative, sealing-wax positive, and all the phenomena thus inverted. Sometimes the most trivial circumstances seem to influence the nature of the electricity excited: when a piece of polished glass, for instance, is rubbed upon rough glass, the former becomes positive, and the latter negative; and if two white silk ribands be drawn crossways over each other, that which is rubbed longitudinally becomes positive, and that rubbed transversely, negative. Indeed, according to Epinus, the effect is variable in one and the same body; for he found that two pieces of clean plate-glass rubbed upon each other were electrical when separated, but, although one was always positive, and the other negative, the same plate sometimes exhibited one, and sometimes the other, electricity.

Very delicate pith-balls, or strips of gold leaf, are usually employed in ascertaining the presence of electricity; and, by the way in which their divergence is affected by glass or sealing-wax, the kind or state of electricity is judged of. When properly suspended or mounted for delicate experiments, they form an *electrometer* or *electroscope*. For this purpose the slips of gold leaf are suspended by a brass cap and wire in a glass cylinder; they



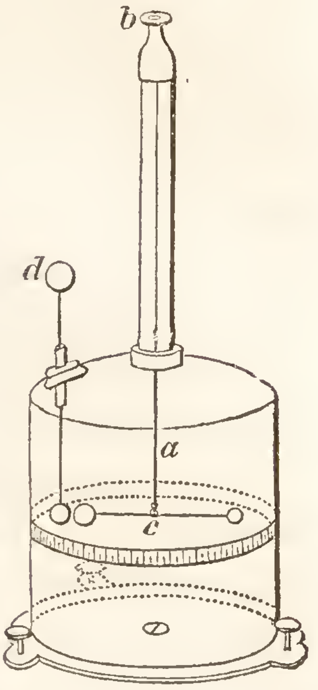
hang in contact when unelectrified; but when electrified they diverge, as in the marginal wood-cut.

When this instrument, as usually constructed, becomes in a small degree damp, its delicacy is much diminished, and it is rendered nearly useless. The following improvement in its construction by the late Mr. Singer renders it a much more sensible and useful instrument. It is constructed as usual, with a glass cylinder, surmounted by a brass cap; but the insulation is made to depend upon a glass tube, about four inches long, and one-fourth of an inch internal diameter, covered both on the inside and outside with sealing-wax, and having a brass wire of a sixteenth or twelfth of an inch thick and five inches long, passing through its axis, so as to be perfectly free from contact with any part of the tube, in the middle of which it is fixed by a plug of silk, which keeps it concentric with the internal diameter of the tube. A, is a brass cap screwed upon the upper part of this wire; it serves to limit the atmosphere from free contact with the outside of the tube, and also defends its inside from dust; to the lower part of the wire the gold leaves are attached, and the whole mounted as usual, and as represented above. When such an electrometer is to be employed in atmospherical investigations, the contrivance described by Mr. Ronalds (*Quar. Journ.* ii. 249) may be conveniently applied to it.



The kind of electricity by which the gold leaves are diverged may be judged of by approaching the cap of the instrument with a stick of excited sealing-wax; if it be *negative*, the divergence will increase; if *positive*, the leaves will collapse, upon the principle of the mutual annihilation of the opposite electricities, or that bodies similarly electrified repel each other, but that when dissimilarly electrified they become mutually attractive.

To ascertain the actual repulsive and attractive powers appertaining to weakly-electrified bodies, M. Coulomb has ingeniously availed himself of the principle of torsion, and has thus constructed his *electrical balance.* It consists of a fine metallic wire, *a,* one end of which is attached to the screw *b,* and to the other is suspended the horizontal needle *c,* composed of gum-lac or other non-conductor, and armed at one extremity with a gilt pith-ball, counterpoised at the other end by an index. The conductor *d*, is a small wire with a ball at each end passing through the glass receiver in which the needle is suspended, and having its lower ball opposed to that of the needle. By the screw *b*, the two balls are brought into contact, and the index then points to *o*, on the divided scale of degrees. On communicating a very feeble electrical power to the conductor, it transfers it to the moveable pith-ball, and repels it a certain number of degrees, proportional to the intensity of the acquired electricity, and measured by the power of torsion which it exerts upon the fine wire. By experiments made with this electrometer, it would appear that the electrical powers follow the law of gravitation, in being in the inverse ratio of the squares of the distances of the acting bodies. In the most delicate construction of the instrument a single silk-worm's thread is used instead of the wire.



Some bodies suffer electricity to pass through their substance, and are called *conductors*. Others only receive it upon the spot touched, and are called *non-conductors*. The former have been erroneously supposed not to become electrical by friction, and have thence been called *non-electrics*: the latter, on the contrary, are called *electrics*, because they evidently acquire electricity by friction. They are also called *insulators*. The metals are all conductors: according to Mr. Harris (*Phil. Trans.* 1827), silver and copper are the best conductors; then gold, zinc, and platinum, iron, tin, and lead. Well burned charcoal and plumbago also conduct. It would appear from M. Pouellet's experiments, that the conducting power of metals is much influenced by their purity, and affected by very small quantities of foreign substances. Thus he found nearly pure silver to have a conducting power = 860. Silver, containing about 6 per cent. of alloy (copper?), had a power = 656 only; and, by 20 per cent. of alloy it was reduced to = 569. Pure gold conducted = 620; but gold of 18 carats only = 109. (See *Quart. Journ. N.S.* iv. 199.) Dry air, glass, sulphur, resins, and oils, are non-conductors. Water, damp wood, spirit of wine, damp air, some oils, and most animals and plants are imperfect conductors.

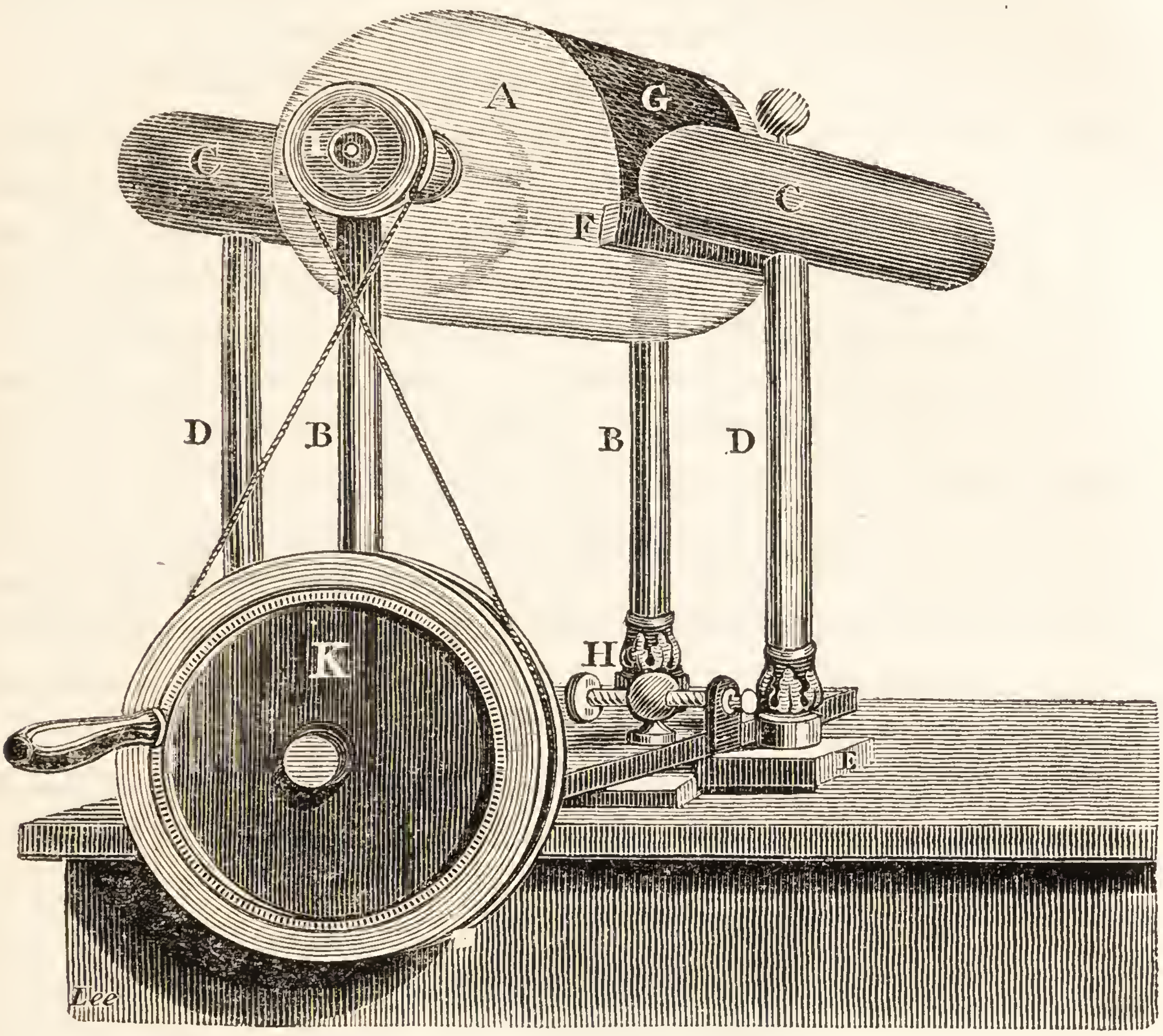
Rarefied air admits of the passage of electricity; so does the Torricellian vacuum: hence, if an electrified body be placed under the receiver of the air-pump, it loses its electricity during exhaustion. So that the air, independent of its non-conducting power, appears to influence the retentive properties of bodies in respect to electricity, by its pressure.

There appears to be no constant relation between the state of bodies and their conducting powers: among solids, metals are conductors, but gums and resins are non-conductors; among liquids, strong alcaline, acid, and saline solutions, are good conductors; water is an imperfect conductor, and oils are non-conductors; solid wax is almost a non-conductor, but when melted, a good one. Conducting powers belong to bodies in the most opposite states; thus the flame of alcohol, and ice, are equally good conductors. (Biot, *Traité de Physique*, tom. ii. p. 213.) Glass is a non-conductor when cold, but conducts when red-hot: the diamond is a non-conductor, but pure and well-burned charcoal is among the best of the non-metallic conductors.

There are many mineral substances which show signs of electricity when heated; as the tourmalin, topaz, diamond, boracite, &c.; and in these bodies the different surfaces exhibit different electrical states. According to M. Haüy, this *pyroelectricity* is of two kinds; the poles of the tourmalin, for instance, when duly heated, are negative and positive, but, as it cools, this electricity disappears; at a lower temperature the poles again resume their power, but in an inverted order. (*Traité de Physique.*)

Whenever one part of a body, or system of bodies, is positive, another part is invariably negative; and these opposite electrical states are always such as exactly to neutralize each other. Thus, in the common electrical machine, one conductor receives the electricity of the glass cylinder, and the other that of the silk rubber, and the former conductor is positive, and the latter negative; but if they be connected, all electrical phenomena cease.

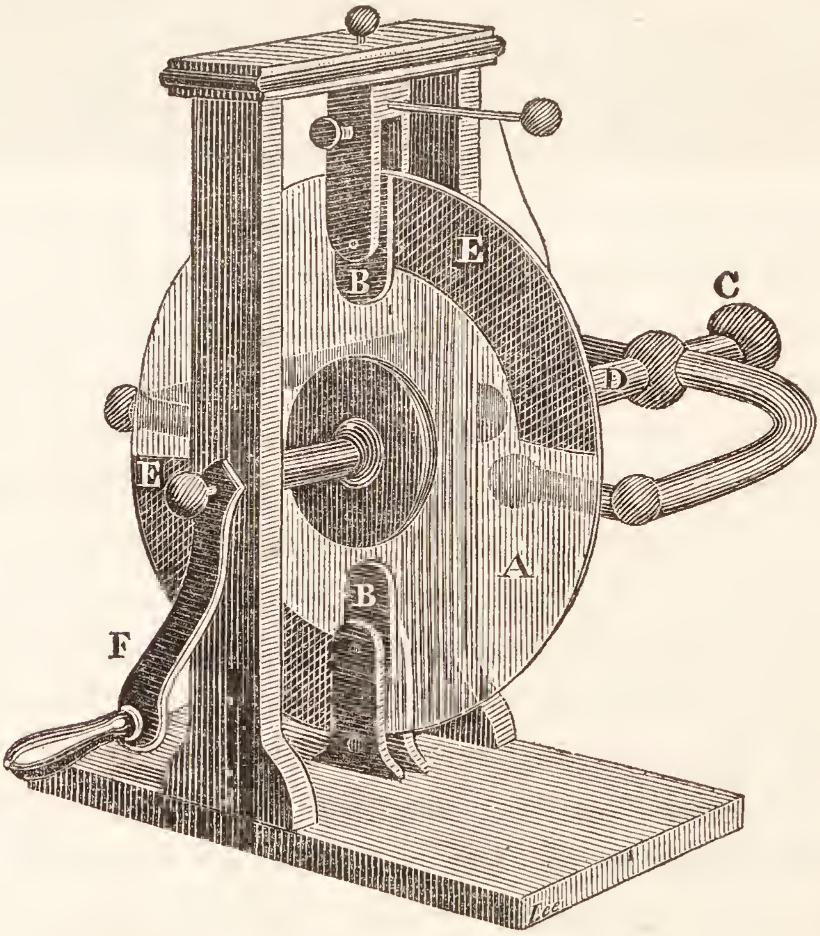
The best electrical machine for experimental purposes is represented in the annexed sketch.



It consists of a glass cylinder A, about 10 or 12 inches in diameter, and 15 to 20 inches in length, turning between two upright pillars of glass, B B, fixed to a stout mahogany base. Two smooth metal conductors, equal in length to the cylinder and about one-third of its diameter, C C, are placed parallel to it upon two glass pillars, D D, which are cemented into two sliding pieces of wood E, by which their distance from the cylinder may be adjusted. One of the conductors has a cushion, F, attached to it by a bent metallic spring, nearly as long as the cylinder, and about one inch or an inch and a half wide, to the upper part of which is sewed a flap of oil silk, G, which should reach from the cushion over the upper surface of the glass cylinder, to within about an inch of a row of points attached to the side of the opposite conductor. The conductor to which the cushion is attached is called the negative conductor; the other collects the electricity of the glass, and is called the positive conductor. H, is an adjusting screw to regulate the pressure of the cushion upon the cylinder. The motion of the cylinder is in the direction of the silk flap, and may be communicated by a handle attached at I, or by the multiplying wheel K. To put this electrical machine into good action, every part should be made perfectly clean and dry. The cushion is then anointed with amalgam, and applied by a gentle pressure to the cylinder. If positive electricity is required, it may be received from the conductor bearing the points, that supporting the cushion being uninsulated by a wire passing from it to the stand; if, on the contrary, negative electricity is required, it may be obtained from the insulated cushion cylinder, the other being uninsulated.

The best *amalgam* is composed of one part of tin and two of zinc melted together, and mixed, while fluid, with six parts of hot mercury in an iron mortar. This mixture is triturated till it becomes a fine powder, which is then formed into a tenacious paste with hog's lard.

Another form of the electrical machine consists of a circular glass plate A, mounted upon an axis, and rubbed by two pairs of cushions, as shown at B B. The brass conductor C has its points opposed to the plate, and is insulated by the glass stem



D. E E are double pieces of oil-silk passing from the cushions to near the points. The whole is supported by a stout mahogany frame, and motion is given to the plate by the winch F.

These electrical machines have considerable power; they are easily cleaned and excited, and are more portable than the cylinders; but as they cannot be conveniently insulated, the negative electrical power cannot be well exhibited, so that for the purposes of experimental research the former machines are preferable.

When the electrical machine is in good order, and the atmosphere dry, it produces a crackling noise when the plate or cylinder is turned, and flashes and sparks of light are seen upon various parts of the glass passing from the cushion to the conductor: if the knuckle be held near the conductor, sparks pass to it through some inches of air, with a peculiar noise, and excite a slightly painful sensation in the part upon which they are received. It is conjectured that the cause of the light thus perceived, is the sudden compression of the air or medium through which the electricity passes, and it is always probably attended by a proportionate elevation of temperature, as is shown by the power of the spark to inflame spirit of wine, fulminating silver, and other easily inflammable compounds.

In these electrical machines the surface of the glass becomes positive by friction upon the rubber or cushion, which becomes negative; and as the cylinder or plate is kept in progressive motion, it follows that, provided there be a means of carrying off its positive electricity, it will continually receive a new supply from the rubber; if, on the contrary, no means of conducting it away be resorted to, it will perpetually annihilate itself by retransmission to the cushion. But it also follows, that when the cushion is insulated, the abduction of electricity must be very limited: hence, to the full and perfect operation of the electrical machine, two circumstances must co-operate; there must be a means of withdrawing the generated electricity from the surface of the glass, and of preserving the supply to the cushion; of these, the former is effected by the opposed points and prime conductor, the latter by connecting the cushion by a metallic chain or wire with the earth. We accordingly observe, in examining the operation of the electrical machine, 1st. That the electricity in either conductor is extremely feeble when they are both well insulated. 2dly. That when one conductor is uninsulated, the power of the other is proportionately augmented; in the positive conductor, because then the other draws uninterrupted supplies from the earth; and in the negative conductor, because the positive freely transmits, and hence leaves it in a state rapidly to receive. 3dly. That the cushion and the surface of the glass are always in opposite states. 4thly. That the negative and positive electricities excited, bear precisely that relation which enables them, when combined, to neutralize each other; in other words, that the deficiency of electricity in the one conductor is exactly such as to be restored by the redundancy in the other.

The law of electrical attraction and repulsion corresponds with that observed in magnetism, the similar poles of magnets repelling and their dissimilar poles attracting each other.

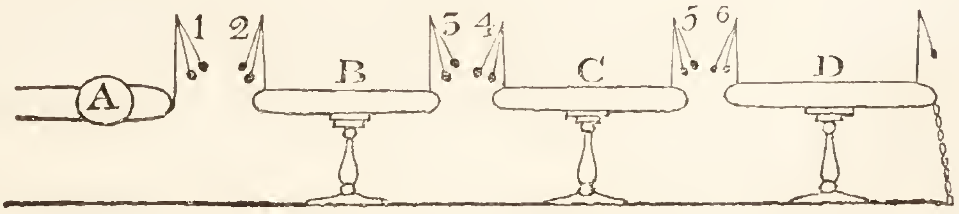
The appearance of the electric light is modified by the density of the medium through which it passes. In common air, short sparks are straight, or nearly so, and long ones zigzag; the former are brilliant, especially at their extremities, the latter usually of a paler or redder hue. In condensed air, the electric spark is bright and white; in rarefied air, it is of a reddish tinge, and faint and divided; in the more perfect vacuum of a good air-pump, it is of a purplish hue, and only visible in a dark room. In a good Torricellian vacuum the light is faint blue; and in the most perfect vacua which can be obtained, it is scarcely visible, and of a greenish tint. In different gases, the electric spark appears most brilliant in those which are most dense; in hydrogen gas, it is faint and red; in carbonic acid, it is vivid and white.

It has been already shown, that when bodies exhibit a mutual electro-attractive power, they are in opposite electrical states, and that when electro-repulsive, they are similarly electrical: now, if we bring any light body near the prime conductor, it will be drawn towards it, even from a considerable distance; whence it would appear, that the mere vicinity of an electrified body is sufficient to confer upon all surrounding bodies an opposite electrical state, independent of any direct communication; indeed, the interposition of a non-conducting medium, such as air, glass, &c. is an essential requisite.

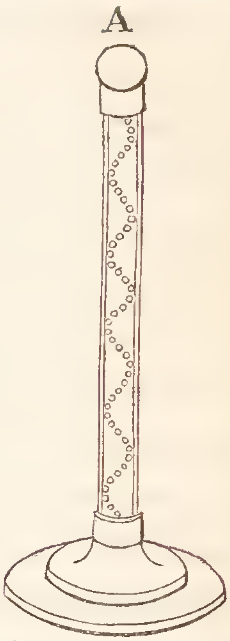
Bodies thus rendered electrical by vicinity or position are said to be electrified by *induction*, and they exhibit in this state some very singular and important properties.

If an insulated conductor be electrified, and an uninsulated conductor be opposed to it, there being between the two a thin stratum of air, glass, or other non-conductor, the uninsulated conductor, under such circumstances, acquires by induction an opposite electrical state to that of the originally electrified insulated conductor. In this case, the induced electricity remains evident, until an explosion, spark, or discharge happens, when the opposite electricities annihilate each other. Induced electricity may thus be exhibited through a long series of insulated conductors, provided the last of the series be communicated with the earth.

Thus, in the following diagram, A may represent the positive conductor of the electrical machine; B, C, and D, three insulated conductors, placed at a little distance from each other, D having a chain touching the ground; then the balls 1, being positive, will attract the balls 2, which are rendered negative by induction. Under these circumstances, each of the conductors becomes polar, and the balls 3 are positive, while 4 are negative, 5 positive, 6 negative, &c.; the central points of the conductors, B C D, are neutral. When these opposite electrical states have arrived at a certain intensity, sparks pass between the different conductors, and the electrical phenomena cease.



The opposite electrical states of these sets of balls may be further proved by approaching the different pairs with excited sealing-wax, by which the series 2, 4, and 6, will be repelled, while 1, 3, and 5 will be attracted, showing that the former are similarly electrical with the wax, or negative, and the latter oppositely electrical or positive.



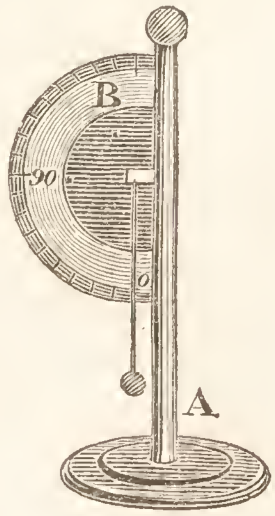
The extent of such a polar arrangement may be greatly increased by pasting small spangles of tin-foil upon a clean plate of glass, within a small distance of each other, each of which will then represent an insulated conductor; and the first spangle being held near the excited conductor of the machine, and the last in the hand, a series of brilliant sparks will pass between each, indicating the annihilation of the opposite electrical states. The *spiral luminous tube*, A, luminous words, flowers, &c., are arrangements of this kind.

If we substitute for air any less moveable and penetrable non-conducting medium, we shall have an opportunity of observing some other curious facts connected with this state of electricity, and of examining the use and construction of several important electrical instruments. Upon the principle of induction through glass it is that the accumulation of electricity in the *Leyden phial* is effected. It consists of a thin glass jar, coated internally and externally with tin-foil to within a short distance of its mouth. When the inner surface is rendered positive by union with the conductor of the electrical machine, the exterior, being connected with the ground, becomes negative by induction. When the inner and outer surfaces are united by a conductor, all electrical accumulation is annihilated by a powerful spark, and the two opposite states are found to have been precisely equivalent. A pane of glass, coated upon both sides to within an inch of its edges with tin-foil, exhibits precisely the same phenomena as the phial; but it is a less convenient form of the apparatus.

If the communication between the opposite surfaces of the Leyden phial be made by the hands, a painful jarring sensation is felt at the joints of the fingers, the elbows, shoulders, and chest, commonly called the *electrical shock*. Metallic wires with balls at their ends, bent, or jointed and fixed to a glass handle, are generally used to transfer the electric charge, and these instruments are called *dischargers*.

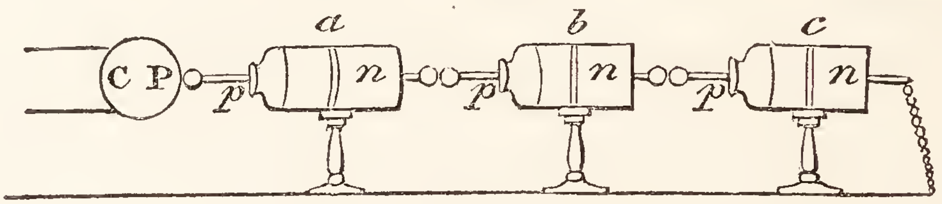
In all cases of electrical accumulation, the surfaces intended to retain it must be free from asperities, and points: a pointed wire held near the prime conductor rapidly discharges it; if it be affixed to the conductor, a similar effect is observed; and upon holding the hand near the point, a peculiar coldness is perceived, which has been called the *electrical aura*, and which depends upon the rapid recession of the electrified air. It is sufficient to blow out a candle, and to communicate motion to light bodies, as seen in electrical fly-wheels, and in models of mills, orreries, and other amusing electro-mechanical apparatus. If the Leyden jar be discharged by a very finely-pointed wire, the electricities quietly annihilate each other, and no explosion can be produced. In these cases the electric fluid appears to become so dense at the extremity of the point, as to overcome those forces which, under other circumstances, retain it upon surfaces, and resist its escape. Whatever these forces may be, they are always the more easily overcome as the electrified body is more pointed and the point more prominent.

To ascertain the relative *charge* which the jar has received, we employ the *quadrant electrometer*, contrived by Henly. It consists of a rounded stem of metal, A, to the side of which is attached an ivory semicircle, B; to the centre is affixed a pin, upon which a very thin piece of cane or ivory, about four inches long, with a pith ball at its lower extremity, turns freely, traversing the semicircle as an index. The lower half of the semicircle is divided into 90°. When not electrified, its index hangs parallel to the stem at 0°, but when electrified, the ball recedes and carries the index over the graduated circle to a greater or less extent, in proportion to the intensity of the electricity.



The annihilation of positive by negative electricity, and *vice versâ*, may be well shown by the following experiment. Attach Henly's quadrant electrometer to the knob of a Leyden jar, and give it a certain charge from the positive conductor: then transfer the jar to the negative conductor, and, whilst receiving a negative charge, the electrometer will fall, indicating the loss of all electrical accumulation; it then will again rise as the jar becomes negatively charged, and may again be discharged by transferring it to the positive conductor.

If one Leyden jar be insulated, with its internal surface connected with the positive conductor, another jar may be charged from its exterior coating; and if this second jar be insulated, a third may be charged from its exterior coating, and so on for any number of jars, provided always that the exterior coating of the last jar be connected with the ground. In this case, a polar arrangement, similar to that of the conductors above described, will have been formed, glass being the medium of induction instead of air.

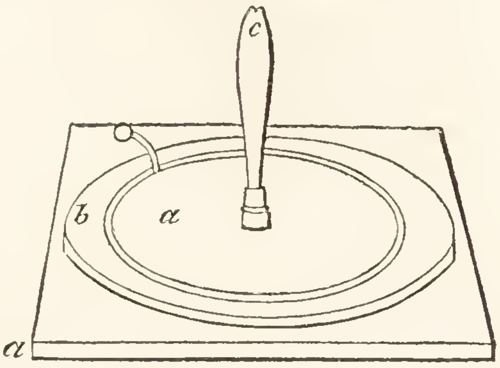


Let C P be the positive conductor of the electrical machine, and *a b c* three insulated Leyden phials, the outer coating of *c* being connected with the ground; it is then obvious, that there will be the same polar state as in the conductors already noticed; that the insides of *a*, *b*, and *c*, will be positive, and the outsides negative; and that, consequently, on removing the jars from each other, they will all be similarly charged; and that if the three inner surfaces *p p p* and the outer surfaces *n n n* be united, the whole may be discharged as one jar.

Upon this principle a jar may be charged by the transfer of its inherent electricity from one surface to the other, by insulating it and connecting its interior coating with the positive conductor, and its exterior with the negative; thus the electricity received by the former is withdrawn from the latter, and the jar becomes charged. This experiment well illustrates the non-conducting power of glass.

The use of the metallic coatings of the Leyden phial is equally to distribute the electricities over the opposite surfaces; for if the coatings be made moveable, the jar remains charged when they are removed. In discharging the jar, too, the annihilation is rendered simultaneous by the conducting coating suffering the transfer of the opposite electricities from every part of the glass surfaces at the same instant.

There are some other electrical instruments the operation of which is referable to the phenomena of *induction*, such as the electrophorus, and the condenser.



The *electrophorus* consists of two metallic plates, *a a*, with an intervening plate of resinous matter, *b*, for which equal parts of shell-lac, resin, and Venice turpentine, are generally used, the mixture being carefully melted in a pipkin, and poured, whilst liquid, into a wooden or metal hoop, of a proper size, placed upon a polished surface of glass or marble, from which it easily separates when cold; it should be about half an inch thick, and the smooth surface being uppermost, the lower side should be covered with tin foil, or attached to any other metallic plate; a polished brass plate, with a glass handle *c* attached to it, is then placed upon the upper surface of the resinous plate, and of rather smaller diameter. The resin is then to be excited with a piece of dry fur, and the instrument will be found to exhibit the following phenomena :—

Upon raising the brass plate by its insulating handle, it will be found very feebly electrical; replace it, touch it with the finger and again lift it off by its handle, and it will give a spark of positive electricity. This process may very often be repeated without fresh excitation, which circumstance, as well as the nature of the electrical charge, shows that the electricity of the moveable brass plate is not directly derived from the resin, but that it depends upon induction: this is more obvious by considering the upper plate, not as in contact with, but merely very near the resinous disc: this, from the minute irregularities upon its surface, is really the case; the negative electricity, therefore, of the excited resinous plate is communicated from a few points of contact to the brass plate, upon its first application, and then the latter is precisely in the state of a conductor opposed to, but not touching, an electrified surface, and consequently in due condition to be rendered electrical by induction, when occasionally uninsulated by the contact of the finger.

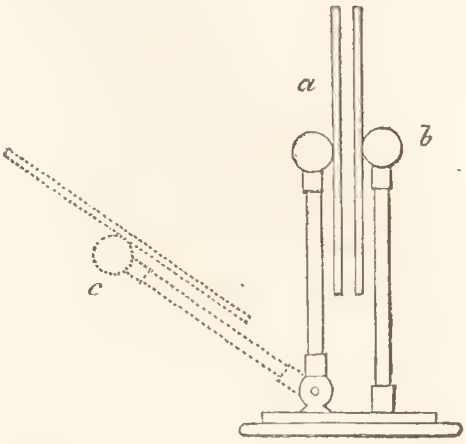
With this instrument, one phenomenon of induction may be shown, which cannot be so well exhibited by any other; namely, the increased capacity for electricity of the conductor under the influence of induction. The brass plate, when placed upon the resin, may be regarded as in a polar state; the lower surface next the resin being positive, the upper surface being negative. Upon touching the upper surface with the finger, it instantly acquires electricity, loses its polarity, and becomes positive, giving, upon removal, a positive spark to any conductor. That the quantity of electricity received from the finger, or other source, is equivalent to that given out, is shown by the following experiment: Place the metallic upon the resinous plate, and touch the former with the knob of a Leyden phial; then touch the cap of an electrometer with the knob of the phial, and it will give a certain negative divergence to the leaves; raise the plate and present the knob of the jar to it, a spark will pass; and upon applying the jar a second time to the electrometer, the leaves will entirely collapse, showing the exact annihilation of the former negative, by the latter positive charge.

When the electrophorus is placed upon an insulating stand, its lower plate is always found in an opposite electrical state to the upper one, so that in this respect its plates resemble the coatings of a Leyden jar.

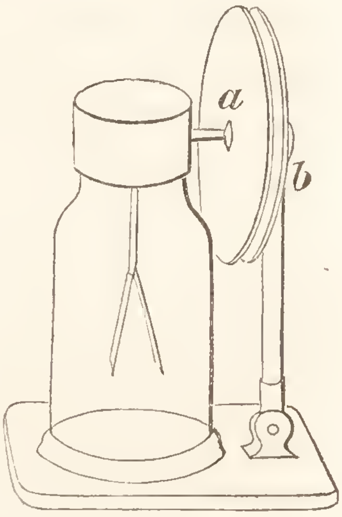
The electrophorus may often be used for the same purposes as the electrical machine, and in the laboratory it furnishes a very convenient substitute for that more expensive piece of apparatus.

When an insulated surface is opposed to another which is not insulated, so as to be affected by it by induction, the electricity communicated to the former suffers a singular increase of tension or intensity on breaking the induction by removing the opposed uninsulated conductor; this property is strikingly exhibited in the following experiment:—Provide a brass plate, three or four inches in diameter, and drop upon its lower surface three small spots of sealing-wax; place it upon a similar plate, forming the cap of the gold-leaf electrometer, from which it will be separated about a twentieth of an inch by the three small insulating legs of wax. Connect the upper plate with the ground, by touching it, and give a very feeble electrical charge to the electrometer, so as scarcely perceptibly to diverge its leaves; then suddenly remove the upper plate, by which the induction will be broken, and the tension of the electricity suddenly increased, so as to cause a very considerable divergence of the leaves.

The plates employed in this experiment have been called *condensers.* They are sometimes placed perpendicularly, and the uninsulated plate *a* is supported by a wire and joint, so as to be brought as close as possible to the insulated plate *b*, without touching; the latter is in communication with the electrometer, and having received its charge, the moveable uninsulated plate is drawn back, as in *c*, and the intensity of the electricity displayed.



Sometimes the condenser is directly attached to the electrometer, as shown in the annexed cut.—*a*, the insulated plate; *b*, the moveable plate in communication with the ground.



Various attempts have been made so to combine electrical condensers, as to multiply their effect, and render very slight electrical changes susceptible of measurement and examination; of this nature is the *Electrical Multiplier,* contrived by Mr. Cavallo, (*Complete Treatise on Electricity*, vol. iii. p. 99); the *Doublers* of Mr. Bennet and Mr. Nicholson (*Phil. Trans.*, lxxvii. and lxxviii.); and Mr. Wilson's *Double Multiplier* (NICHOLSON's *Journal,* ix.): but the complexity of these instruments, as Mr. Singer has remarked, renders their results equivocal, and often has a tendency to produce the electrical states, independent of the intended source, or to change that originally communicated.

Electricians generally employ the term *quantity* to indicate the absolute quantity of electric power in any body, and the term *tension* or *intensity* to signify that state of electricity indicated by an electrometer, or its power of passing through a certain stratum of air or other ill-conducting medium.

If we suppose a charged Leyden phial to furnish a spark, when discharged, of one inch in length, we should find that another uncharged Leyden phial, the inner and outer coating of which were communicated with those of the former, would, upon the same quantity of electricity being thrown in, reduce the length of the spark to half an inch; here, the *quantity* of electricity remaining the same, its *intensity* is diminished by one-half, by its distribution over the larger surface.

It is obvious, that the extension of surface alluded to in the last paragraph, will be attended with a greater superficial exposure to the unelectrified air; and hence it might be expected, that a similar diminution of intensity would result from the vicinity of the electrified surface to the ground, or to any other body of sufficient magnitude in its ordinary state. That this is the case, may be shown by diverging the leaves of the gold leaf electrometer, and in that state approaching the instrument with an uninsulated plate, which, when within half an inch of the electrometer plate, will cause the leaves to collapse; but on removing the uninsulated plate, they will again diverge, in consequence of the electricity regaining its former intensity. The same fact is shown by the condensing electrometer.

The power of the Leyden jar is proportioned to its surface, but a very large jar is inconvenient, and difficult to procure; the same end is attained by arranging several jars, so that by a communication existing between all their interior coatings, their exterior being also united, they may be charged and discharged as one jar. Such a combination is called an electrical *Battery*, and is useful for exhibiting the effect of accumulated electricity.

The discharge of the battery is attended by a considerable report, and if it be passed through small animals, it instantly kills them; if through fine metallic wires, they are ignited, melted, and burned; and gunpowder, cotton sprinkled with powdered resin, and a variety of other combustibles, may be inflamed by the same means.

Another effect of the transfer of electricity through metals, is the production of magnetism, a current of which appears to be put in motion in the wire, and to move at right angles to the supposed direction of the electrical current; but these phenomena admit of the best illustration by Voltaic electricity, and will therefore be examined into when the construction and phenomena of the Voltaic apparatus have been explained.

There are many other sources of electricity than those just noticed. When glass is rubbed by mercury, it becomes electrified, and this is the cause of the luminous appearance observed when a barometer is agitated in a dark room, in which case flashes of light are seen to traverse the empty part of the tube. Even the friction of air upon glass is attended by electrical excitation; for Mr. Wilson found, that by blowing upon a dry plate of glass with a pair of bellows, it acquired positive electricity. Whenever bodies change their forms, their electrical states are also altered. Thus the conversion of water into vapour, the evolution of gaseous bodies, and the congelation of chocolate and of melted resins and sulphur, are processes in which electricity is also rendered sensible.

Electricity is also generated by the disruption of solid bodies, as by breaking a mass of sugar, tearing asunder the plates of mica, cleaving a piece of dry warm wood, and breaking one of those pieces of unanealed glass called Rupert's drops. Change of temperature is a remarkable source of electricity in some crystallized bodies; some varieties of the tourmaline, when exposed to a temperature of 212°, or somewhat above it, become electro-polar; and in that prismatic variety, of which one end terminates by a six, and the other by a three-sided pyramid, the former becomes positive, and the latter negative; in this mineral the electricity is retained long after the cooling of the crystal. Certain topazes, the boracite, prismatic calamine, and a few other minerals, have been shewn to possess analogous properties to those of the tourmaline.

When an insulated plate of zinc is brought into contact with one of copper or silver, it is found, after removal, to be positively electrical, and the silver or copper is left in the opposite state. In these cases of *electrical excitation by contact of different metals*, the most oxidizable metal is always positive, in relation to the least oxidizable metal, which is negative, and the more opposite the metals in these respects, the greater the electrical excitation; and if the metals be placed in the following order, each will become positive by the contact of that which precedes it, and negative by the contact of that which follows it; and the greatest effect will result from the contact of the most distant metals.

Platinum.
Gold.
Silver.
Mercury.
Copper.
Iron.
Tin.
Lead.
Zinc.

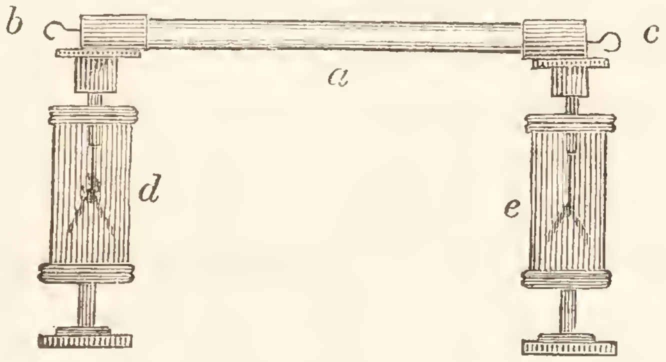
If the nerve of a recently-killed frog be attached to a silver probe, and a piece of zinc be brought into the contact of the muscular parts of the animal, violent convulsions are produced every time the metals thus connected are made to touch each other; exactly the same effect is produced by an electric spark, or the discharge of a very small Leyden phial.

If a piece of zinc be placed upon the tongue, and a piece of silver under it, a peculiar sensation will be perceived every time the two metals are made to touch.

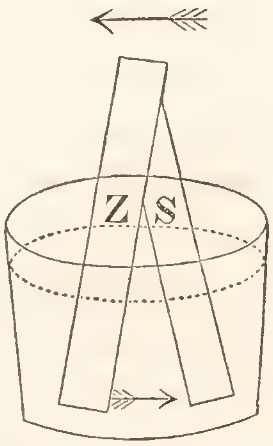
In these cases *the chemical properties of the metals are observed to be affected.* If a silver and a zinc wire be put into a wine-glass full of dilute sulphuric acid, the zinc wire only will evolve gas; but upon bringing the two wires in contact with each other, the silver will also copiously produce air bubbles.

If a plate of iron and one of silver be immersed separately into a solution of sulphate of copper, the iron will acquire a cupreous coating, but the silver remain clean; if we now bring the ends of the plates into contact, copper will presently be deposited upon the silver also. These cases are here only alluded to as proving the influence of electrical over chemical action; and many analogous and familiar instances of the chemical effects of the contact of metals might be adduced. Thus we observe brass cocks in leaden cisterns corroded at the junction; and the places where solder is applied are liable to depositions from the water; iron nails, affixing copper to ships' bottoms, are rapidly corroded, whilst the copper itself is protected by them. Iron railings are apt to be decayed and dissolved, where lead is used to fix them in stone cavities; and where iron is employed in fixing or supporting a bronze statue, my friend Mr. Chantrey informs me that it prevents the acquisition of the desirable green rust.

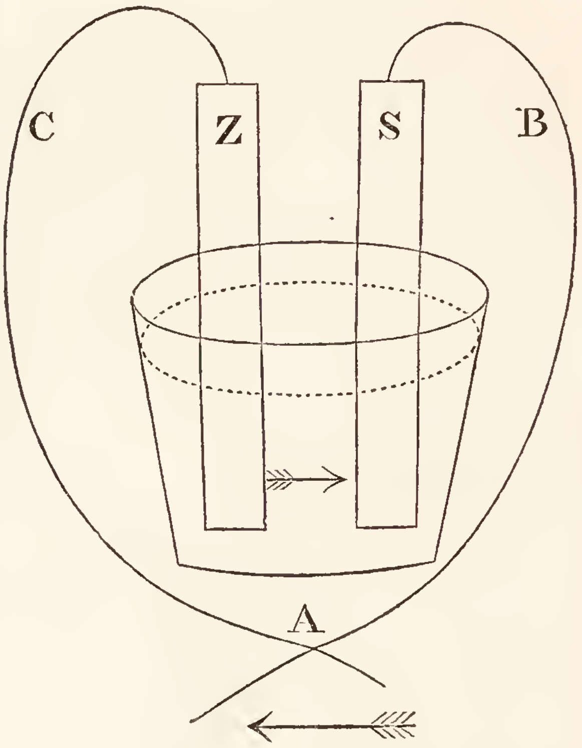
If a number of alternations be made of copper or silver leaf, zinc leaf, and thin paper, the electricity excited by the contact of the metals will be rendered evident to the common electrometer:—*a* represents a glass tube, in which are regularly arranged a number of alternating plates of silver, zinc, and thin paper, forming De Luc's *electrical column.* The metallic cap *b* is in contact with the silver plate, and *c* with the zinc plate, at the respective extremities of the pile. Upon examining the electrometers, it will be found that *d* is negatively diverged, and *e* positively.



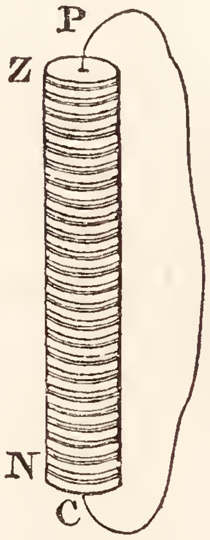
What is commonly called *a simple galvanic circle*, is formed by partially immersing two different metals in a dilute acid, and making a communication between them, either by direct contact, or by some perfect conductor; one of the metals should be easily, and the other difficultly, or not at all acted upon by the liquid, and the more opposite the metals are in these respects, the more powerful are the electrical effects observed. In the annexed cut, Z represents a plate of zinc, and S one of silver, partly immersed in very dilute sulphuric acid, and in contact at their upper ends, and by such arrangement a current of electricity appears to be put in motion, passing from the zinc to the acid, from the acid to the silver, and from the silver again to the zinc.



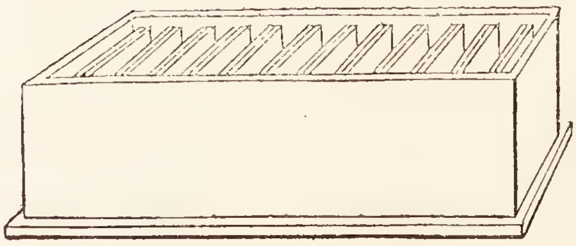
This arrangement may be modified, by immersing the plates separately in the acid, and connecting them by wires, as in the following wood-cut: the *circuit* will thus be extended, but the electrical current will be found moving in the same direction from the zinc towards the silver, and through the wires from the silver to the zinc, in the direction represented by the arrows. In thus completing the circuit by wires, the electric current may continually be transferred through fluid and other bodies, and the circuit may be broken and restored at pleasure, by alternately separating and renewing the contact of the wires at A. It will be observed, that in consequence of the direction of the electric current in this arrangement, the wire B connected with the silver plate is conveying electricity to the wire C, united to the zinc plate. Hence B is considered as positive, and C as negative.



If an arrangement of metallic plates, corresponding with that of De Luc's column, be made with paper moistened with brine, or a weak acid, it will be found, on bringing a wire communicating with the last copper-plate into contact with the first zinc plate, that a spark is perceptible, and also a slight shock, provided the number of alternations be sufficiently numerous. This is the Voltaic *pile*.



Several modes of constructing this apparatus have been adopted, with a view to render it more convenient or active. Sometimes double plates of copper and zinc soldered together are cemented into wooden troughs in regular order, the intervening cells being filled with water, or saline or acid solutions.



Another form consists in arranging a row of glasses, containing dilute sulphuric acid, in each of which is placed a wire or plate of silver or copper, and one of zinc, not touching each other, but so connected by metallic wires, that the zinc of the first cup may communicate with the copper of the second; the zinc of the second with the copper of the third, and so on throughout the series, as represented in the annexed cuts.

Fig. 1.

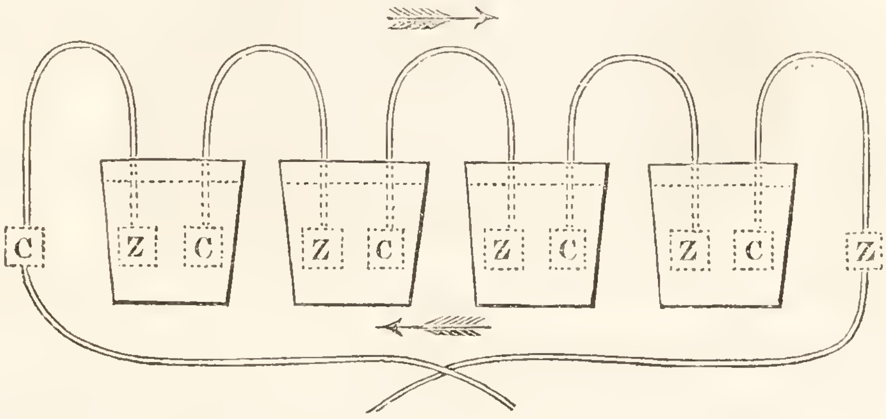
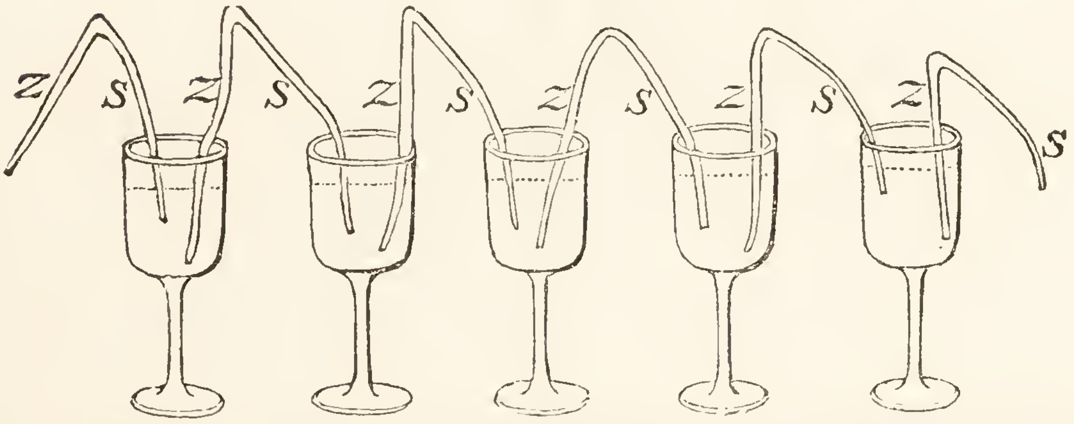
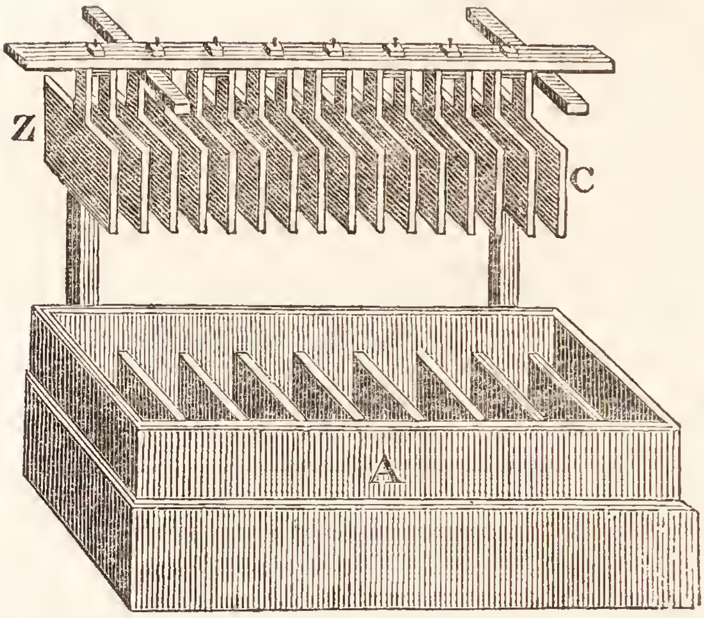


Fig. 2.



By applying the moistened fingers to the extreme wires, a shock will be felt; and on making a communication between them by a wire, it will be found that the copper plates in *Fig.* 1, and the silver wires in *Fig.* 2, instantly acquire the power of decomposing the dilute sulphuric acid, and that the chemical action of the zinc is much augmented. One advantage of this arrangement over the former, is, that both surfaces of the metal are exposed; whereas in the other, by soldering the plates together, its action is diminished.

In the following sketch, the trough A is made of earthenware, with partitions of the same material, and the metallic plates are attached to a bar of wood, arranged as in *Fig.* 1, so that they can be immersed and removed at one operation. The troughs are filled with dilute acid, and by uniting them in regular order, the apparatus may be enlarged to any extent. This is, on the whole, the best form of the Voltaic instrument



hitherto devised, and it is thus that the great apparatus of the Royal Institution was constructed*.

In these arrangements, the terms positive and negative, as applied to the zinc and copper or silver ends of the compound pile, are exactly the reverse of those applied to the simple circle,—a difference which it is necessary to understand, as it has given rise to much ambiguity. It will be observed, that the actual direction of the electric current is the same in both cases, but in the simple circle the conducting wire communicates directly with the plate in contact with the fluid part of the apparatus, while in the compound circle it is connected not with the plate necessarily immersed, but with that associated with it, and therefore of a different kind. Dr. Roget has well illustrated this result by remarking, that the compound circle reduced to its condition of greatest simplicity, would be represented by the following series, consisting of five parts, namely:

Copper—zinc—fluid—copper—zinc.

In this arrangement the copper end is negative, and the zinc end positive. By merely removing the two terminal plates, which in fact are no way concerned in the effect, we bring it to the state of the single circle, consisting simply of

Zinc—fluid—copper,

in which we find the zinc end negative, and the copper positive.

When from 500 to 1000 double plates are rendered active by

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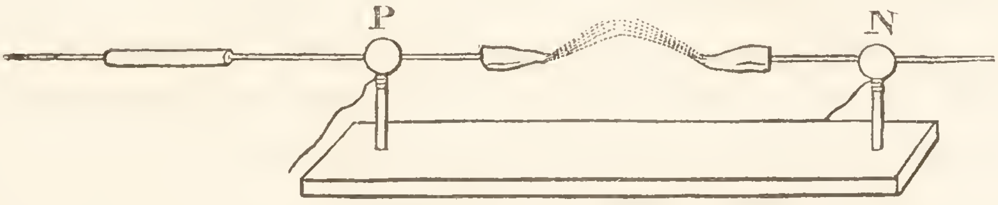
* A very elegant and commodious arrangement of the Voltaic apparatus is described by Mr. Pepys in the *Quarterly Journal,* vol. i., p. 393.

immersion into a liquid consisting of about sixty parts of water with one of nitric and one of sulphuric acid, very brilliant effects are produced when the opposite *poles* are properly united by conductors. Thus, if a piece of charcoal united with the negative wire be made to touch another piece united with the positive wire, a bright spark and intense ignition ensue, and by slowly withdrawing the points from each other, a constant current of electricity takes place through the heated air, producing a magnificent arc of intense light, in the form here represented.



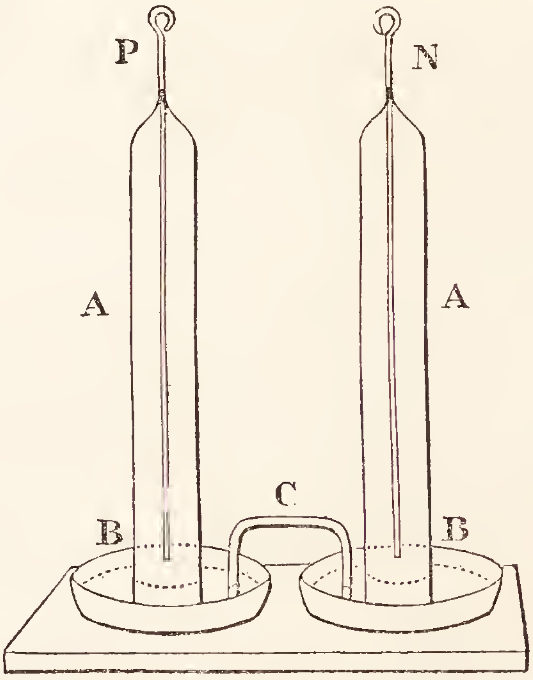
When the metals and other inflammable bodies are placed in this arc of fire they burn with great brilliancy, and those which are most difficult of fusion give evidence of the intensity of the heat by instantly melting; and some earthy and other bodies infusible by ordinary methods are liquefied by the same means. The shock is painful and dangerous. When the communication between the points of charcoal is made in rarefied air, the annihilation of the opposite electricities takes place at some inches' distance, producing a stream of deep purple light.

On immersing the wires from the extremes of this apparatus into water, it is found that the fluid suffers decomposition, and that oxygen gas is liberated at the positive wire or pole, and hydrogen gas at the negative pole.

Many other substances are decomposed with similar phenomena, the inflammable element being disengaged at the negatively electrical surface; hence it would appear, upon the principle of similarly electrified bodies repelling each other, and dissimilarly electrified bodies attracting each other, that the inherent or natural electrical state of the inflammable substances is *positive*, for they are attracted by the negative or oppositely electrified pole; while the bodies, called supporters of combustion, or acidifying principles, are attracted by the positive pole, and, therefore, may be considered as possessed of the *negative* power.

It deserves, however, here to be noticed, that no true electro-chemical decomposition can take place without the intervention of water, dry bodies being either non-conductors or not decomposable. The inflammable, or electro-positive elements follow the hydrogen in these decompositions to the negative pole; and the supporters of combustion or electro-negative bodies associate with the oxygen at the positive pole. Potassa, for instance, cannot be decomposed without the presence of water, when the hydrogen and the potassium collect at the negative pole, and the oxygen of the water and of the alcali are evolved together at the positive pole.

When bodies are under the influence of electrical decomposition, their usual chemical energies are suspended, and some very curious phenomena are observed, which may be illustrated by the following experiments.



Fill the glass tubes A A, which are closed at top and open at bottom, with infusion of violets, or red cabbage, and invert them in the basins B B, containing a solution of Glauber's salt, and connected by the glass tube C, also containing the blue infusion. P and N are platinum wires, which pass into the tubes nearly to the bottom, and which are to be connected with the positive and negative extremities of the Voltaic apparatus. It will be found that oxygen is evolved at the wire P, and hydrogen at N, derived from the decomposition of the water. The Glauber's salt, which consists of sulphuric acid and soda, will also be decomposed; and the blue liquor will be rendered red in the positive vessel, by the accumulation of sulphuric acid, and green in the negative, by the soda, while the acid and alcali will each traverse the tube C without uniting, in consequence of being under the influence of electrical attraction.

The most difficultly decomposable compounds may be thus resolved into their component parts by the electrical agency; by a weak power the proximate elements are separated, and by a stronger power these are resolved into their ultimate constituents; and there is no known compound capable of resisting such decomposition; accordingly, electricity becomes a powerful agent in the hands of the chemist, often enabling him to detect minute portions of foreign matter, and to pronounce upon the nature of a substance whether it be simple or compound. He also, by the same means, modifies the ordinary chemical actions of bodies; by conferring similar electricities upon them they become mutually repulsive, and will not unite, though, under ordinary circumstances, they may be powerfully chemically attractive of each other; on the contrary, by conferring dissimilar electricities upon two bodies possessed of feeble mutual attractions, they may be made to combine. If silver be immersed in water it is not acted upon by that fluid, but if it be rendered positive by connexion with the Voltaic battery, it becomes oxidized by attracting the electro-negative element of the water, namely, the oxygen. If a piece of sheet copper be immersed in dilute nitric acid, it is acted upon, and decomposes the acid; but if it be rendered electro-negative, it is then repulsive of the acid, or of the electro-negative element of the acid, and is not acted upon. This principle was proposed by Sir H. Davy to be applied to the protection of the copper sheathing of ships, which becomes oxidized and corroded by the action of sea-water, but which is not thus acted upon if rendered negative by the contact of zinc or iron. A small piece of iron thus attached to the copper, protects it therefore from this corrosive action, and from oxidizement generally; but it unfortunately renders it at the same time attractive of the electro-positive bodies in the water, such as earthy matters, which are more speedily precipitated upon its surface than they otherwise would be, and give it a coating which prevents corrosion, but which is very favourable to the attachment of weeds and animals, and these render the protected bottoms so foul, as to interfere with the sailing of the vessels.

All bodies which exert powerful chemical agencies upon each other when freedom of motion is given to their particles, render each other oppositely electrical when acting as masses. Hence Sir H. Davy, the great and successful investigator of this branch of chemical philosophy, has supposed that electrical and chemical phenomena, though in themselves quite distinct, may be dependent upon one and the same power, acting in the former case upon masses of matter, in the other upon its particles. This hypothesis has been by some carried so far, as to refer not merely the attractive powers, but the heat and light manifested in many chemical operations to the agency of electricity. When, for instance, a disc of sulphur and one of copper are brought into contact, they become negative and positive, acting as masses: a moderate degree of heat exalts these opposite electrical states; but when the heat is so intense as to fuse the sulphur, and if the copper be also mechanically comminuted, the substances melt together, and much heat and light are evolved in consequence of the annihilation of the opposite electricities which results during the formation of the new compound, which is sulphuret of copper.

The power of the Voltaic apparatus to communicate divergence to the electrometer, is most observed when it is well insulated and filled with pure water. This I had a good opportunity of witnessing in the large battery of 2000 plates, constructed under the direction of Mr. Pepys, for the London Institution. When quite new and clean, it was insulated upon wine bottles, and charged with river water; it gave a powerful shock, much resembling that of a Leyden phial, and required some minutes to recharge itself; the sparks were feeble, but it was extremely and permanently active upon the electrometer, and a pith-ball attached by a thread to its positive pole was eagerly attracted at some distance by another attached to its negative pole. But, with all this manifestation of electricity, its chemical or decomposing energies were feeble in the extreme.

The power of producing ignition and of giving shocks, and of producing the other effects observed when the poles of the apparatus are connected, are much augmented by the interposition of saline solutions and dilute acids, which act chemically upon one of the plates: here, the insulation is not of consequence, and is interfered with by the production of vapour, but the quantity of electricity is much increased, a circumstance which may, perhaps, be referred to the increase of the positive energy of the most oxidable metal by the contact of the acid. In experiments made with the great battery of the Royal Institution, it has been found that 120 plates, rendered active by a mixture of one part of nitric acid and three of water, produced effects equal to 480 plates rendered active by one part of nitric acid and fifteen of water. The nature, however, and the strength of the acid may vary with the size of the battery and the purposes to which it is to be applied. According to Mr. Singer, muriatic acid produces the most permanent effect in the proportion of 1 to 20 parts of water, where the series is not very extensive.

Independently of the action of the acid liquid used in its excitation, the *intensity* of the electricity of the Voltaic apparatus increases with the number of alternations, but the *quantity* is increased by extending the surface of the plates. Thus, if a battery, composed of thirty pairs of plates two inches square, be compared with another battery of thirty pairs of twelve inches square, charged in the same way, no difference will be perceived in their effects upon bad or imperfect conductors; their powers of decomposing water and of giving shocks will be similar; but upon good conductors the effects of the large plates will be considerably greater than those of the small; they will ignite and fuse large quantities of platinum wire, and produce a very brilliant spark between charcoal points. The following experiment well illustrates the different effects of quantity and intensity in the Voltaic apparatus.

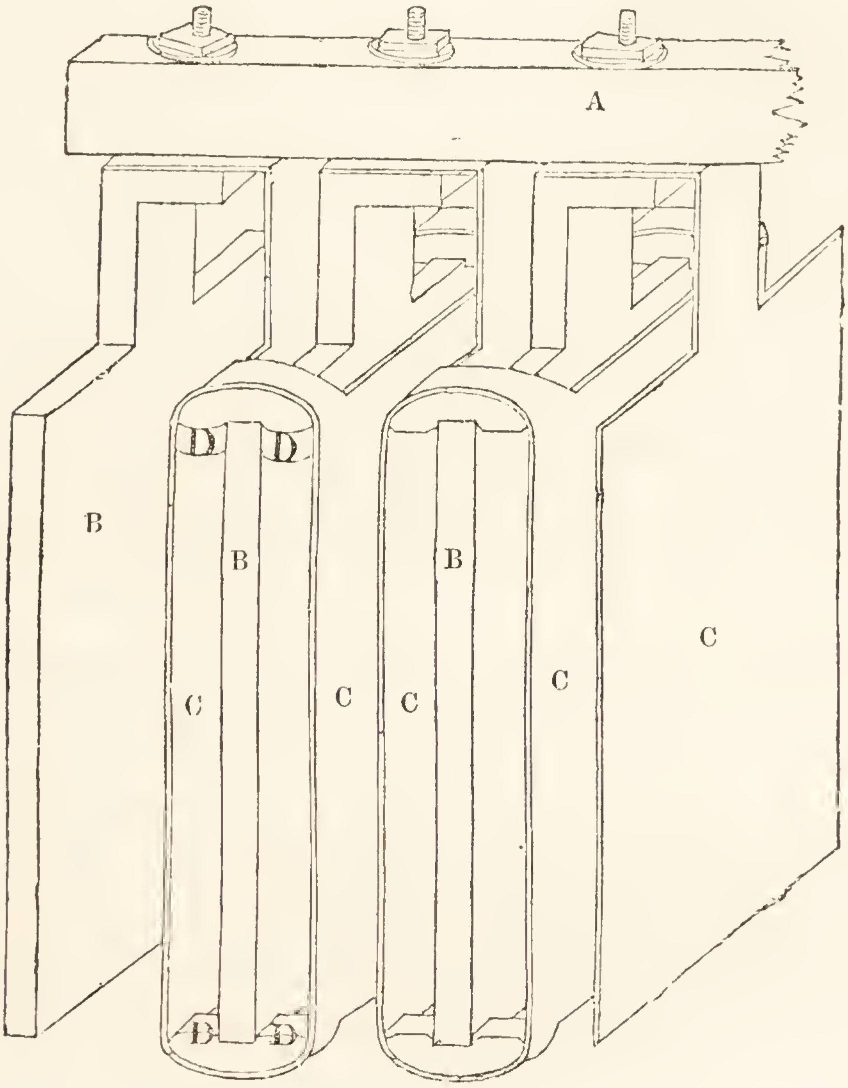
Immerse the platinum wires connected with the extremity of a charged battery composed of twelve-inch plates into water, and it will be found that the evolution of gas is nearly the same as that occasioned by a similar number of two-inch plates. Apply the moistened fingers to the wires, and the shock will be the same as if there were no connexion by the water. While the circuit exists through the human body and the water, let a wire attached to a thin slip of charcoal be made to connect the poles of the battery, and the charcoal will become vividly ignited. The water and the animal substance discharge the electricity of a surface probably not superior to their own surface of contact with the metals; the wires discharge all the residual electricity of the plates; and if a similar experiment be made on plates of an inch square, there will scarcely be any sensation when the hands are made to connect the ends of the battery, a circuit being previously made through water; and no spark, when charcoal is made the medium of connexion, imperfect conductors having been previously applied.

These relative effects of quantity and intensity were admirably illustrated by the experiments instituted by Mr. Children, who constructed a battery, the plates of which were two feet eight inches wide, and six feet high. They were fastened to a beam suspended by counterpoises from the ceiling of his laboratory, so as to be easily immersed into or withdrawn from the cells of acid. The effects upon metallic wires and perfect conductors were extremely intense; but upon imperfect conductors, such as the human body, and water, they were feeble.—*Phil. Trans.*, 1815, p. 363.

When the extremes of a battery composed of large plates are united by wires of different metals, it is found that some are more easily ignited than others, a circumstance which has been referred to their conducting powers: thus, platinum is more easily ignited than silver, and silver than zinc. If the ignition be supposed to result from resistance to the passage of electricity, we should say that the zinc conducted better than silver, and the silver than platinum. In regard to the conducting power of liquids, some interesting experiments may be made by the Voltaic pile. By immersing one of the conductors into the fluid, and then bringing the other (a point of charcoal for instance) to its surface, a spark may be taken upon some fluids, the concentrated acid and alcaline solutions, for instance, and some saline liquids; while others do not admit such transference; and others, as most oils, appear absolute non-conductors. The following Table is drawn up from the experiments of M. Foerstemann. The first column of figures indicates the specific gravity of the liquid; the second the quantity of electricity conducted in equal times; and the third the time required for the conduction of equal quantities. (*Quarterly Journal*, *N.S.* iv. 200.)

Muriatic acid . . .	1.126	2.464	0.410
Acetic acid . .	1.024	2.398	0.423
Nitric acid . . .	1.236	2.283	0.438
Ammonia . .	0.936	2.177	0.459
Sol. muriate of ammonia .	1.064	1.972	0.509
Sulphuric acid . .	1.848	1.737	0.575
Sol. of potassa . .	1.172	1.709	0.585
Sol. of common salt .	1.166	1.672	0.598
Sol. of acetate of lead . .	1.132	1.560	0.632
Distilled water . .	1.000	1.000	1.000

An important improvement has been suggested in the construction of the Voltaic apparatus by Dr. Wollaston (*Annals of Philosophy*, Sept. 1815,) by which great increase of *quantity* is obtained without inconvenient augmentation of the size of the plates: it consists in extending the copper plate, so as to oppose it to every surface of the zinc, as seen in the annexed cut. A is the rod of wood to which the plates are screwed:



B B the zinc plates connected as usual with the copper plates C C, which are doubled over the zinc plates, and opposed to them upon all sides, contact of the surfaces being prevented by pieces of wood or cork placed at D D.

With a single pair of plates of very small dimensions constructed upon this principle, Dr. Wollaston succeeded in fusing and igniting a fine platinum wire. From the experience which I have had of this construction, I am inclined to consider it the most economical and useful form of the Voltaic apparatus; certainly, at least, it is so for all those researches in which there is an occasional demand for quantity as well as intensity of electricity; and such a battery of 120 pairs is adequate to the illustration of all the most important experiments and researches connected with the subject.

The theory of the Voltaic pile is involved in many difficulties. The original source of electricity appears to depend upon the contact of the metals, for we know that a plate of silver and a plate of zinc, or of any other difficultly and easily oxidable metals, become negative and positive on contact. The accumulation must be referred to *induction*, which takes place in the electrical column through the very thin stratum of air or paper, and through water when that fluid is interposed between the plates. Accordingly we observe that the apparatus is in the condition of the series of conductors with interposed air and of the Leyden phials. When the electric column is insulated, the extremities exhibit feeble negative and positive powers; but if either extremity be connected with the ground, the electricity of its poles or extremities is greatly increased, as may be shewn by the increased divergence of the leaves of the electrometer which then ensues.

Dr. Wollaston and some other eminent philosophers have contended that chemical action is the real source of the electricity of the common machine and of the pile (*Phil. Trans.* 1800); but this opinion has been successfully opposed by Sir H. Davy (*Elements of Chem. Phil.* 163). "Zinc and copper," he observes, "different metals and oxalic acid, different metals and sulphur, or charcoal, exhibit electrical effects after mere contact, and that in cases when not the slightest chemical change can be observed; and if in these experiments chemical phenomena are produced by the action of menstrua, all electrical effects immediately cease: and it is not philosophical to assume a cause to account for an effect, when no such cause can be perceived.

"It has been supposed that the action of the common electrical machine depends upon the oxidation of the amalgam; but I found by mounting a small machine in a glass vessel, in such a manner that it could be made to revolve in any species of gas, that it was active in hydrogen gas, and more active in carbonic acid gas than in the atmosphere (probably owing to its greater density). The experiment has been several times repeated under different circumstances, and uniformly with the same results ; and may be regarded as decisive in this important question.

" Electrical effects are exhibited by the same bodies, when acting as masses, which produce chemical phenomena when acting by their particles; it is not therefore improbable, that the primary cause of both may be the same, and that the same arrangements of matter, or the same attractive powers, which place bodies in the relations of positive and negative, *i. e.* which render them attractive of each other electrically, and capable of communicating attractive powers to other matter, may likewise render their particles attractive, and enable them to combine, when they have full freedom of motion.

" It is not a little in favour of this hypothesis, that heat, and sometimes heat and light, result from the exertion of both electrical and chemical attractive powers ; and that by rendering bodies, which on contact are in the relation of positive to others, still more highly positive, their powers of combination are increased ; whereas, when they are placed in a state corresponding to the negative electrical state, their powers of union are destroyed. That acids can be detached from alcalies, oxygen and chlorine from inflammable matter by metallic substances, or by a fluid menstruum highly positive, is likewise favourable to the supposition.

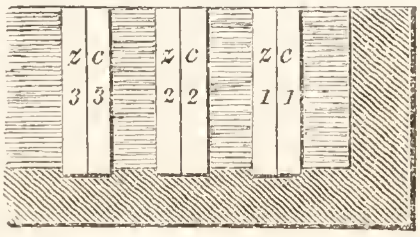
" This view of the possibility of the dependence of electrical and chemical action upon the same cause has been much misrepresented. It has been supposed that the idea was entertained, that chemical changes were occasioned by electrical changes; than which nothing is further from the hypothesis, which I have ventured to advance. They are conceived, on the contrary, to be *distinct* phenomena ; but produced by the *same power*, acting in one case on masses, in the other case on particles. The hypothesis has been attempted to be controverted by experiments which are far from satisfactory, and some of which have no connexion with it. It has been said that acids rendered positive by the common machine, will still combine with alcalies, and that other contradictory results may be obtained ; but a non-conducting acid, though brought in contact with a positive surface, electrified by the common machine, is not rendered positive throughout; but gains a polar electricity, which extends only to a certain depth into the crystals, and the exterior surface, if electrical at all, is negative; and if a wire, positively electrified by the common machine, be introduced into an acid solution, this solution, if at all affected, when made to act upon another solution, will be negative at its point of action; that is, it will be positive near the wire, but will be in the opposite state with regard to another surface. And common electricity is too small in quantity, in its usual form of application, to influence chemical changes; for it requires a very strong machine acting upon a very small surface, to produce any sensible polar decompositions of bodies.

"The power of action of the Voltaic apparatus seems to depend upon causes similar to those which produce the accumulation in the Leyden battery, namely, the property of non-conductors and imperfect conductors to receive electrical polarities from, and to communicate them to conductors; but its permanent action is connected with the decomposition of the chemical menstrua between the plates. Each plate of zinc is made positive, and each plate of copper negative, by contact; and all the plates are so arranged with respect to each other as to have their electricities exalted by induction, so that every single polar arrangement heightens the electricity of every other polar arrangement; and the accumulation of power increases with the number of the series. When the battery is connected in a circle, the effects are demonstrated by its constant exhibition of chemical agencies, and the powers exist as long as there is any menstruum to decompose: but when it is insulated, and the extreme poles of zinc and copper are unconnected, no effects whatever are perceived to take place, no chemical changes go on, and it exhibits its influence only by communicating very weak charges to the electrometer, the end terminated by zinc communicating a positive charge, that terminated by copper, a negative charge.

"That each plate of the most oxidable metal in the apparatus is in the relation of positive, and each plate of the least oxidable, in the relation of negative, and that every series is possessed of similar and equal polarity, is shewn by a very simple experiment: forty rods of zinc of the same size, connected with forty silver wires precisely similar, were introduced in the regular order into similar glasses filled with a solution of muriate of ammonia, rendered slightly acid by muriatic acid ; as long as the extreme parts remained unconnected, no gas was disengaged from the silver, and the zinc was scarcely acted upon ; when they were connected, all the plates of zinc were dissolved much more rapidly, and hydrogen gas was evolved from every silver wire. And in another experiment, in which several of these wires at equal distances were introduced into small glass tubes, it was found that equal quantities of hydrogen were produced."

Sir Humphry further remarks, that there are no fluids, except such as contain water, which are capable of being made the medium of connexion between the metals of the Voltaic apparatus, and refers the activity of De Luc's column to the moisture adhering to the paper discs. This, however, appears to me to admit of doubt.

In discussing the theory of the pile, Dr. Henry observes, (*Elements*, 1826, vol. i. p. 188,) " that the concentration which takes place at the zinc end of the arrangement, admits of being explained by the hypothesis of Volta, especially as modified by Sir H. Davy. Taking the first cell as an example, the fluid interposed between the positive zinc plate *z* 1, and negative copper plate *c* 2, being itself a conductor of electricity, must in time produce an equilibrium between these two plates ; but this can only be done by the passage of a certain quantity of electricity across the fluid. The absolute quantity of electricity will, therefore, be diminished in the first pair, and increased in the second. In like manner, the second zinc plate will give up part of its electricity to the third copper plate, and the second pair of plates will be deprived of part of its electricity. The electricity, thus lost by the second pair, it will regain from the first pair of plates. By multiplying, in this way, the number of plates, every successive pair, as we advance in the series, has a tendency to diminish the quantity of electricity in the first, and to have its own state of electricity proportionally exalted.



" When a communication is made between two extremities of a series, for example, between *z* 3 or its contiguous cell, and *c* 1, the opposite electricities tend to an equilibrium. The third pair gives up a share of its electricity to the first; and the intermediate pair, being placed between equal forces, remains in equilibrio. Hence, in every galvanic arrangement, there is a pair of plates at the centre, which is in its natural state of electricity. The effect of such a communication must necessarily be to reduce the pile to a state of inactivity, if there did not still exist some cause sufficient to destroy the equilibrium. On the hypothesis of Volta, this can be nothing else than the property of electro-motion in the metals, which originally produced its disturbance.

In regard to the hypotheses, Dr. Henry adds, that have been framed to explain the phenomena of the Voltaic pile, in the present state of the science, no one of them is entitled to be received as altogether satisfactory; "and I have stated them rather with the view of exciting than of satisfying inquiry *."

In their ordinary electrical phenomena the identity of Voltaic and common electricity are easily discerned; but the chemical agencies of the former are so much more obvious and decided than those of the latter, as to lead some to regard them in this respect as essentially different. Dr. Wollaston's inquiries have thrown much light upon this subject, and he refers the differences to the great quantity and small intensity of the electricity of the pile. By a peculiar adaptation of apparatus he succeeded in effecting the essential cases of decomposition by the common machine.

It had been thought necessary to employ powerful machines and large Leyden jars for the decomposition of water; but when he considered that the decomposition must depend on duly proportioning the strength of the charge of electricity to the quantity of water, and that the quantity exposed to its action at the surface of communication, depends on the extent of that surface, by reducing this, he effected the decomposition of water by a much smaller machine. Having procured

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* The reader who wishes to pursue the subject may consult an essay by Dr. Henry, in Nicholson's Journal, xxxv. 259; M. De Luc's papers, xxxii. 271, and xxxvi. 97; Mr. Singer on the Electrical Column, xxxvi. 373, and his work on Galvanic Electricity; Dr. Bostock's Essay in Thomson's Annals, iii. 32; Sir H. Davy's chapter on Electrical Attraction and Repulsion, in his Elements of Chem. Philos., p. 125; and the 1st vol. of Gay Lussac and Thenard's Recherches.

a small wire of fine gold, and given it as fine a point as he could, he inserted it into a capillary glass tube, and after heating the tube so as to make it adhere to the point, and cover it in every part, he gradually ground it down, till with a pocket lens he could discover that the point of the gold was exposed.

The success of this method exceeding his expectations, he coated several wires in the same manner, and found, that when sparks from the conductors before mentioned were made to pass through water, by means of a point so guarded, a spark passing to the distance of one-eighth of an inch, would decompose water, when the point exposed did not exceed 1-700th of an inch in diameter. With another point, which he estimated at 1-1500th, a succession of sparks, 1-20th of an inch in length, afforded a current of small bubbles of air. But in every way in which he tried it, he observed that each wire gave both oxygen and hydrogen gas, instead of their being formed separately as by the electric pile.

Dr. Wollaston coated the middle of a very fine silver wire, for two or three inches, with sealing-wax, and by cutting it through in the middle of the wax, exposed a section of the wire. The two coated extremities of the wire thus divided, were immersed in a solution of sulphate of copper, placed in an electric circuit between the two conductors of a cylindrical machine; and sparks taken at 1-10th of an inch distance, were passed by means of them through the solution. After 100 turns of the machine, the wire which communicated with what is called the negative conductor, had a precipitate formed on its surface, which on being burnished, was evidently copper; but the opposite wire had no such coating.

Upon reversing the direction of the current of electricity, the order of the phenomena was of course reversed; the copper being shortly redissolved by assistance of the oxidating power of positive electricity, and a similar precipitate formed on the opposite wire.

A similar experiment, made with gold wires $\frac{1}{100}$ of an inch diameter, in a solution of corrosive sublimate, had the same success.

Having coloured a card with a strong infusion of litmus, he passed a current of electric sparks along it, by means of two fine gold points, touching it at the distance of an inch from each other. The effect, as in other cases, depending on the smallness of the quantity of water, was most discernible when the card was nearly dry. In this state a very few turns of the machine were sufficient to occasion a redness at the positive wire, very manifest to the naked eye. The negative wire being afterwards placed on the same spot, soon restored it to its original blue colour.

As general changes in the form and constitution of matter are connected with its electrical states, it is obvious that electricity must be continually active in nature. Its effects are exhibited on a magnificent scale in the thunder-storm, which results from the accumulation of electricity in the clouds, as was first experimentally demonstrated by Dr. Franklin, who also first showed the advantage of pointed conductors as safeguards to buildings. In these cases the conducting rod or rods should be of copper or iron, and from half to three-fourths of an inch diameter. Its upper end should be elevated three or four feet above the highest part of the building, and all the metallic parts of the roof should be connected with the rod, which should be perfectly continuous throughout, and passing down the side of the building, penetrate several feet below its foundation, so as always to be immersed in a moist stratum of soil, or, if possible, into water. The leaden water-pipes attached to houses often might be made to answer the purpose of conductors, especially when thick enough to resist fusion.

During a thunder-storm the safest situation is in the middle of a room, at a distance from the chimney, and standing upon a woollen rug, which is a non-conductor. Blankets and feathers being non-conductors, bed is a place of comparative safety, provided the bell-wires are not too near, which are almost always melted in houses struck by lightning. When out of doors, it is dangerous to take shelter under trees: the safest situation is within some yards of them, and upon the dryest spot that can be selected.

The discharge of electricity in a thunder-storm is sometimes only from cloud to cloud; sometimes from the earth to the clouds; and sometimes from the clouds to the earth, as one or other may be positive or negative. When aqueous vapour is condensed, the clouds formed are usually more or less electrical; and the earth below them being brought into an opposite state, by induction, a discharge takes place when the clouds approach within a certain distance, constituting lightning; and the undulation of the air, produced by the discharge, is the cause of thunder, which is more or less intense, and of longer or shorter duration, according to the quantity of air acted upon, and the distance of the place where the report is heard from the point of the discharge. It may not be uninteresting to give a further illustration of this idea: electrical effects take place in no sensible time; it has been found that a discharge through a circuit of four miles is instantaneous; but sound moves at the rate of about twelve miles in a minute. Now, supposing the lightning to pass through a space of some miles, the explosion will be first heard from the point of the air agitated, nearest to the spectator; it will gradually come from the more distant parts of the course of the electricity, and last of all, will be heard from the remote extremity; and the different degrees of the agitation of the air, and likewise the difference of the distance, will account for the different intensities of the sound, and its apparent reverberations and changes.

"In a violent thunder-storm, when the sound instantly succeeds the flash, the persons who witness the circumstance are in some danger; when the interval is a quarter of a minute, they are secure."—Davy's *Elements*, p. 139.

A variety of electrical apparatus has been devised to illustrate the operation of conductors for lightning, and the advantage of points over balls; the simplest consists of a model of a house having a conductor with a break in it, in which some inflammable matter should be placed; the lower end of the conductor should be communicated with the exterior of a charged Leyden phial, the knob of which, brought over its upper end, will then represent a thunder-cloud. If the conductor be pointed, it will be slowly discharged; if surmounted by a ball, there will be an explosion, and the combustibles probably inflamed.

The coruscations of the *aurora borealis* are also probably electrical, and much resemble flashes of electric light traversing rarefied air. The *water-spout* may be referred to the same source, and is probably the result of the operation of a weakly electrical cloud, at an inconsiderable elevation above the sea brought into an opposite electrical state; and the attraction of the lower part of the cloud, for the surface of the water, may be the immediate cause of this extraordinary phenomenon.

In the *gymnotus* or *electric eel*, and in the *torpedo* or *electric ray*, are arrangements, given to those remarkable animals for the purposes of defence, which certain forms of the Voltaic apparatus much resemble, for they consist of many alternations of different substances. These electrical organs are much more abundantly supplied with nerves than any other part of the animal, and the too frequent use of them is succeeded by debility and death.—Todd, *Phil. Trans.*, 1817.

That arrangements of different organic substances are capable of producing electrical effects, has been shown by various experimentalists. If the hind legs of a frog be placed upon a glass plate, and the crural nerve dissected out of one made to communicate with the other, it will be found, upon making occasional contacts with the remaining crural nerve, that the limbs of the animal will be agitated at each contact. These circumstances have induced some physiologists to suppose that electricity may be concerned in some of the most recondite phenomena of vitality, and Dr. Wollaston, Sir E. Home, and myself, have made some experiments tending to confer probability on this idea.—*Phil. Trans.*, 1809.

We have as yet no plausible hypothesis concerning the *cause* of electrical phenomena, though the subject has engaged the attention of the most eminent philosophers of Europe. They have been by some referred to the presence of a peculiar fluid existing in all matter, and exhibiting itself by the appearances which have been described, whenever its equilibrium is disturbed, presenting negative and positive electricity when deficient and when redundant. Others have plausibly argued for the presence of two fluids, distinct from each other. Others have considered the effects as referable to peculiar exertions of the attractive powers of matter, and have regarded the existence of any distinct fluid or form of matter to be as unnecessary to the explanation of the phenomena, as it is in the question concerning the cause of gravitation.

When the flame of a candle is placed between a positive and negative surface, it is urged towards the latter; a circumstance which has been explained upon the supposition of a current of electrical matter passing from the positive to the negative pole; indeed, it has been considered as demonstrating the existence of such a current of matter. But if the flame of phosphorus be substituted for that of a candle, it takes an opposite direction; and, instead of being attracted towards the negative, it bends to the positive surface. It has been shown that inflammable bodies are always attracted by negative surfaces, and acid bodies, and those in which the supporters of combustion prevail, are attracted by positive surfaces. Hence the flame of the candle throwing off carbon, is directed to the negative pole, while that of phosphorus, forming acid matter, goes to the positive, consistently with the ordinary laws of electro-chemical attraction.—*Phil. Trans.*, 1814.

There are other experiments opposed to the idea that electricity is a material substance. If we discharge a Leyden phial through a quire of paper, the perforation is equally burred upon both sides, and not upon the negative side only, as would have been the case if any material body had gone through in that direction. The power seems to have come from the centre of the paper, as if one-half of the quire had been attracted by the positive, and the other by the negative surface.

When a pointed metallic wire is presented towards the conductor of the electrical machine, in a darkened room, a star of light is observed when the conductor is positive, but a brush of light when it is negative; a circumstance which has been referred to the reception of the electric fluid in the one case, and its escape in the other. In the Voltaic discharge the same appearances are evident upon the charcoal point, rays appearing to diverge from the negative conductor, while upon the positive a spot of bright light is perceptible. But these affections of light can scarcely be considered as indicating the emission or reception of any specific form of matter.

Electro-magnetism.—Certain analogies between the phenomena of electricity and those of magnetism are so obvious, as long to have led to the supposition of some intimate mutual relation existing between those powers of matter. The subject has lately received important elucidation from the researches of Oersted and others, and upon these has been founded a new and highly interesting department of science. The chief investigations connected with it belong rather to physical than chemical philosophy; but as they are susceptible of some applications to the inquiries of the chemist, it becomes necessary here to give such statement of them as may render them intelligible. The reader who may be desirous of historical details and references to authors, may advantageously consult Mr. Faraday's "Historical Sketch of Electro-magnetism."—*Ann. of Phil., N. S.*, vol. ii.

A metallic wire which is transmitting an electric current, the connecting wire, for instance, between the extremes of the Voltaic apparatus, if brought towards a magnetic needle, has the power of attracting and repelling it in obedience to certain laws.

If a magnetic needle be left to take its natural direction, and then a straight portion of the connecting wire be brought above it and parallel to it, that end of the needle next the negative pole of the battery moves towards the west, and that whether the wire be on one or other side of the needle, so that it be above and parallel to it. If the connecting wire be sunk on either side of the needle, so as to come into the horizontal plane in which the needle is allowed to move, there is no motion of the needle in that plane, but the needle attempts to move in a vertical circle, and but for the imperfect suspension and the earth's magnetism, would do so. When the wire is on the east of the needle, the pole next the negative end of the battery is elevated, and when on the west of the needle it is depressed. If the connecting wire be now sunk below the level of the needle, similar attractions and repulsions take place, but in opposite directions to those followed when it is above. The pole of the needle opposite the negative end of the battery now moves eastwards, whatever the position of the wire, so that it be restricted as above.

The nature of the connecting wire, provided it be metallic, does not materially interfere in these phenomena; a tube filled with mercury is effectual. It continues, also, though the conductor be interrupted by water, unless the interruption be of great extent. The magnetic influence of the wire also extends through all sorts of substances, as is the case with common magnetism. It does not act on needles of brass, glass, or gum lac.

If an unmagnetised steel needle be placed parallel to, and in contact, or nearly so, with the connecting wire, it acquires opposite magnetisms upon its two sides; but if it be placed at *right angles* to the connecting wire it becomes polar, and is a permanent magnet. All these facts may be observed by the electricity of the common machine, but it is inconveniently employed, in consequence of the deficiency in quantity of electricity. Those forms of the Voltaic apparatus which generate *quantity*, are such as produce the most decided electro-magnetic effects;—they appear to be independent of tension, and, accordingly, a single pair of very large plates is more effectual than a numerous succession of small ones. Batteries constructed for the purpose, of one or more pairs of large plates, have sometimes been termed *magneto-motors*.

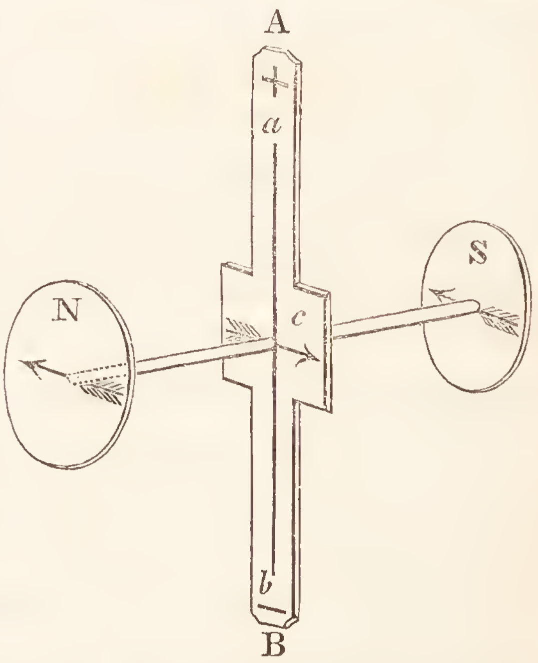
That attraction and repulsion may be communicated to metallic wires by the electric current alone, independent of a magnet, is shewn by placing two wires parallel to each other, and so suspended as to move freely when transmitting the electricity of the battery. If the current pass along both wires in the same direction they attract, if in opposite directions they repel each other. If, also, the one wire being fixed and the other moveable, the currents be sent in opposite directions, then the moveable wire will turn round until they are in the same direction. Mr. Faraday observes, "that the contrast between these attractions and repulsions, and those usually called electrical, are very striking. These take place only when the circuit is completed; those, only when it is incomplete. The attractions take place between the similar ends of the wires, and the repulsions between the dissimilar ends; but the electrical attractions take place between dissimilar ends, and the repulsions between similar ends. These take place in vacuo, but those do not. When the magnetic attraction brings the two wires together, they remain in contact; but when electrical attraction brings two bodies together, they separate after the contact."

The Voltaic pile itself acts upon a magnetic needle in the same manner as the connecting wire. When placed near a pile or trough in action, having its poles connected by a wire, it immediately moves, becoming obedient to the battery in the same manner as to the connecting wire, so that the needle becomes an instrument competent to indicate that state of an active Voltaic pile, and of the wire connecting it, which is supposed to be occasioned by currents of electricity. The needle thus applied, is sometimes called a *galvanometer.*

It has already been stated, that the connecting wire confers magnetism upon steel; that it is itself everywhere a magnet, is shown by presenting iron-filings to any part of it, which are instantly attracted by and cluster round it, but fall off almost the instant that the connexion with the battery is broken.

Having ascertained that the action of the connecting wire on the direction of the magnet is owing to a tendency which they have to revolve round each other, Mr. Faraday contrived an apparatus, by means of which either pole of a magnet was made to revolve round a wire as a fixed point. The description of this instrument, which has been the parent of a great variety of analogous revolving apparatus, is given at length in the 12th volume of the *Quarterly Journal.*

The phenomena which have been adverted to, may be explained by the hypothesis of Dr. Wollaston; upon the supposition of the existence of an electro-magnetic current or vortex passing round the axis of the wire, and apparently at right angles to the electric current. The direction of the magnetic current, as dependent upon that of electricity, *is* demonstrated by the affections of the approximated pole of the magnet, and by its rotation, where it has freedom of motion; and the following contrivance of Dr. Roget is useful in assisting the memory repecting the details of these affections. A B (see the wood-cut) is a slip of card, on each side of which a line *a b* is drawn along the middle of its length, the end *a* being marked +, the end *b* —, and the centre *c*, being crossed by an arrow at right angles to it directed as in the figure. Through the centre and at right angles to the plane of the slip of card, there is made to pass a slender stem of wood, at the two ends of which are fixed, in planes parallel to the slip of card A B, the circular discs of card, marked respectively with the letters N and



S, and with arrows parallel to, but pointing in a contrary direction to the one at *c*. The same marks must be put on the reverse of each of the three pieces of card, so that when held in different situations they may be seen without turning the instrument.

If the line *a b* be supposed to represent the galvanic wire (the direction of the current of electricity being denoted by the signs + and —, at the ends of the line), the arrow at the centre will point out the direction in which it tends to move, when under the influence of the north pole of a magnet situated at N; or of a south pole situated on the other side at S: and, *vice versâ*, the arrows at N and S will indicate the directions in which the north and south pole, respectively, tends to revolve round the galvanised wire in its vicinity, with relation to the direction of the current of electricity that is passing through it.

It must be observed that the poles N and S are here not considered as in connexion with each other, or as forming parts of one magnet: their operations are exhibited singly, and quite independently of each other. The advantage of this little instrument consists in its being capable of being held in any situation, and thus easily adapted to the circumstances of any fact or experiment, of which we may wish to examine the theory.

If the conducting wire be twisted into a helix or spiral form, by rolling it round a solid rod or a glass tube, it will in some respects represent a polar magnet, and a piece of steel introduced into the central cavity of such a spiral speedily becomes powerfully magnetic. For these purposes wire, covered with silk, is conveniently used, as it may be closely coiled without allowing the passage of electricity from surface to surface, and it will be found that if such a coil have freedom of motion,—if, for instance, it be floating about in a basin of water, it will be obedient to the poles of the magnet, mutually attracted and repelled by them, and forms what may be called a Voltaic magnet. Ampere, whose theory of electro-magnetism deserves to be attentively studied [*], terms such an arrangement an *electrodynamic cylinder*.

If a magnetic needle be longitudinally surrounded by several

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[*] See an able article upon this subject in the *Quarterly Review*, xxxv. 237.

convolutions of wire, covered with silk to prevent electric communication between its different parts, a deflection from its meridian will be occasioned by the transmission of the minutest quantity of electricity through the coil. In this way the electricity produced by the contact of metals, by their immersion in acid and other solutions, and by mere changes of their temperature, may be rendered evident. M. Schweigger, who thus first applied the magnetic needle to such detection of quantitative electricity, has termed the above arrangement an *Electro-Magnetic Multiplier.—Ann. of Phil., N. S.*, vol. v., p. 436.

CHAPTER II.

OF RADIANT OR IMPONDERABLE MATTER.

Of the substances belonging to our globe, some are of so subtile a nature as to require minute and delicate investigation demonstrate their existence; they can neither be confined, nor submitted to the usual modes of examination, and are known only in their states of motion as acting upon our senses, or as producing changes in the more gross forms of matter. They have been included under the general term of Radiant or Imponderable Ethereal Matter, which, as it produces different phenomena, must be considered as differing either in its nature or affections. Respecting the nature of these phenomena, two opinions have been entertained, and each ably supported. It has been supposed by Huygens and Descartes, that they arise from vibrations of a rare elastic medium which fills space; while Newton has considered them as resulting from emanations of particles of matter. The former opinion has been ably advocated by Dr. Young, who has selected from Newton many passages favourable to the undulating theory, and has shown that it explains many phenomena not easily consistent with the theory of radiating particles. (Young's *Nat. Phil.* vol. ii. p. 631. See also Fresnel's Exposition of the Undulatory Theory in the first volumes of the *Quarterly Journal, N. S.*)

The other forms of matter are tangible and ponderable, and, therefore, easily susceptible of accurate examination; they may be considered as resulting from the mutual agencies of heat and attraction, and are comprehended under the three classes of *Solids*, *Liquids*, and *Gases* or *Vapours*.

Section I. Of the Effects of Radiant Matter in producing the Phenomena of Vision.

The minute investigation of those laws of light which relate to its motion, and effects in producing vision, constitutes a branch of the science of Optics, and, therefore, belongs to Mechanical Philosophy ; it is, however, requisite that some of them should partially be considered as bearing upon important questions of chemical inquiry.

The phenomena of vision are produced either by bodies inherently luminous, such as the sun, the fixed stars, and incandescent substances; or they are referable to the reflection of light from the surfaces of bodies. It is thus that the objects around us are visible by reflecting the sun's rays in the day-time, but become lost in obscurity when that luminary sinks beneath the horizon.

The manner in which the eye is affected by luminous bodies shows that light is transmitted in right lines, and every right line drawn from a luminous body to the eye is termed a *ray of light*, and as a congeries of rays possesses the same properties as the single ray, the same abstract term is frequently employed to designate the congeries.

The discoveries of Roemer, (*Phil. Trans.* vol. xii.) and of Bradley, (*Phil. Trans.* vol. xxxv. and xlv.) have shown that light is about eight minutes and thirteen seconds in passing from the sun to the earth, so that it may be considered as moving at the rate of 200,000 miles in a second.

Some bodies intercept light, or are *opaque ;* others allow its transmission, or are *transparent ;* and there are gradations from perfect opacity to nearly perfect transparency, as we see in *semitransparent* or *translucent* bodies. It is probable that opacity results from the attraction of the substance for light, and not from its density, for it can scarcely be supposed that the particles of bodies should not be far enough distant to allow of the passage of light. Newton supposes the particles of transparent bodies to be of uniform density and arrangement, and attracting the ray of light equally in every direction, they suffer it to pass through them without obstruction ; whereas, in opaque bodies, the particles are either of unequal density or irregularly arranged, and the light being unequally attracted, cannot, therefore, penetrate the body.

When a ray of light passes through the same medium, or when it passes perpendicularly from one transparent medium into another, it continues to move without changing its direction; but, when it passes obliquely from one medium into another of a different density, it is thrown more or less out of its old direction, and is said to be *refracted*. The refraction is *towards* the perpendicular when the ray passes into a denser medium, and *from* the perpendicular when it passes into a rarer medium. The medium in which the rays of light are caused to approach nearest to the line perpendicular to its surface, is said to have the greatest refractive density.

The density of bodies is by no means the only circumstance that affects their refractive power, it also depends upon their chemical nature; and, generally speaking, those substances have the greatest refractive power which are combustible, or which contain an inflammable basis. The refractive power of compounds is not the mean deduced from that of their components; which, however, it generally is in mere mixtures. The following table exhibits the refractive powers of several gaseous bodies, from the experiments of Biot and Arago, at the temperature of 32 F., and under mean barometrical pressure.

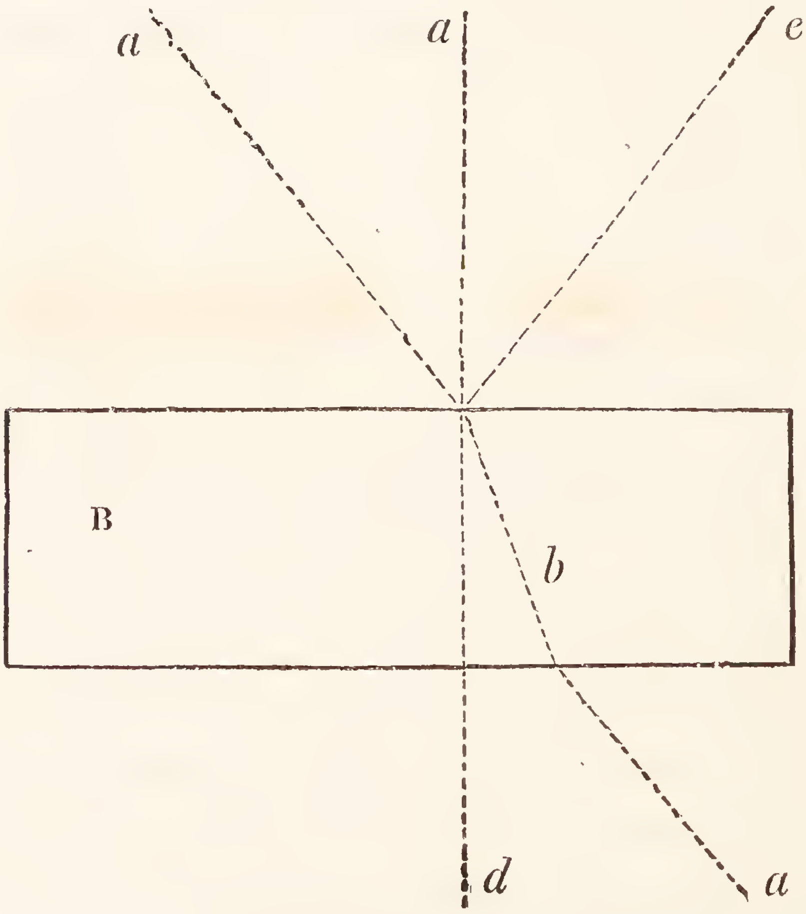
Atmospheric air	1.00000
Oxygen	0.86161
Nitrogen	1.03408
Hydrogen	6.61436
Ammonia	2.16851
Carbonic acid	1.00476
Carburetted hydrogen	2.09270
Muriatic acid gas	1.19625

Dr. Wollaston invented an apparatus in which, by means of a rectangular prism of flint glass, the index of refraction of substances may be read off at once by a vernier, the three sides of a moveable triangle performing the operation of reduction in a very compendious manner. As the chemical constitution of bodies may in many instances be inferred from their refractive power, Dr. Wollaston has suggested the application of such an instrument for discovering the purity of essential oils: in oil of cloves, for instance, he found a wide difference in refractive power, that of the genuine oil being as high as

1.535, while other samples did not exceed 1.498, and were probably adulterated. (*Phil. Trans.* 1802.) In thus employing this instrument, however, it must be recollected that the refractive power of the same oil distilled at different times will vary. This, at least, I have found to be the case with oil of peppermint, different specimens of which, all genuine, varied from 1.462 to 1.488.

When the rays of light arrive at the surfaces of bodies, a part of them, and sometimes nearly the whole, is thrown back, or *reflected,* and the more obliquely the light falls upon the surface, the greater in general is the reflected portion. In these cases the angle of reflection is always equal to the angle of incidence.

Let *a a* represent pencils of light falling upon the surface of a polished piece of glass B, the perpendicular pencil will pass on in a straight line to *d.* Of the oblique pencil, one portion will enter the glass and suffer refraction towards the perpendicular as at *b*, and re-entering the atmosphere, it will bend from the perpendicular, and re-assume its former direction, as at *c.* Another portion of the oblique pencil will be reflected at an angle equal to that of its incidence, as at *e.*



When a ray of light passes through an oblique angular crystalline body, it exhibits peculiar phenomena; one portion is refracted in the ordinary way; another suffers extraordinary refraction, in a plane parallel to the diagonal joining the two obtuse angles of the crystal; so that objects seen through the crystal appear double. Transparent rhomboids of carbonate of lime, or Iceland crystal, exhibit this phenomenon of *double refraction* particularly distinct.

If a ray of light, which has thus suffered double refraction, be received by another crystal, placed parallel to the first, there will be no new division of the rays; but if it be placed in a transverse direction, that part of the ray which before suffered ordinary refraction will now undergo extraordinary refraction, and reciprocally that which underwent extraordinary refraction now suffers ordinary refraction.

If the second crystal be turned gradually round in the same plane, when it has made a quarter of a revolution, there will be four divisions of the ray, and they will be reduced to two in the half of the revolution; so that the refracting power appears to depend upon some relation of the position of the crystalline particles.

When light is reflected from bodies, it retains, under many circumstances, its former relations to the refractive power of transparent media; but, in certain cases, at angles differing for different substances, the reflected rays exhibit peculiar properties, analogous to those which have suffered extraordinary refraction. Thus, if the flame of a taper reflected at an angle of 52° 45′ from the surface of water, be viewed through a piece of doubly refracting spar, one of the images will vanish every time that the crystal makes a quarter of a revolution.

When a ray of light is made to fall upon a polished glass surface, at an angle of incidence of 35° 25′, the angle of reflection will be equal to that of incidence. Let us suppose another plate of glass so placed that the reflected ray will fall upon it at the same angle of 35° 25′; this second plate may be turned round its axis without varying the angle which it makes with the ray that falls upon it. A very curious circumstance is observed as this second glass is turned round. Suppose the two planes of reflection to be parallel to each other; in that case the ray of light is reflected from the second glass in the same manner as from the first. Let the second glass be now turned round a quadrant of a circle, so as to make the reflecting planes perpendicular to each other: now, the whole of the ray will pass through the second glass, and none of it will be reflected. Turn the second glass round another quadrant of a circle, so as to make the reflecting planes again parallel, and the ray will again be reflected. When the second glass is turned round three quadrants, the light will be again transmitted, and none of it reflected. Thus, when the reflecting planes are parallel, the light is reflected; but when they are perpendicular the light is transmitted. This experiment proves, that, under certain circumstances, light can penetrate through glass when in one position, but not in another. This curious fact was first observed by Malus, who accounted for it by supposing the particles of light to have assumed a particular position, as a needle does when under the influence of a magnet, and hence he called this property of light its *polarisation*. (Thomson's *System*, vol. i. p. 16.) It has since been studied with laborious diligence by Dr. Brewster, and by MM. Arago and Biot.—*Phil. Trans.* 1813, 1814, 1815, 1816, 1817; *Annales de Chimie*, tom. 94; *Traité de Physique.*

If plates of mica, and certain other crystallized substances, be placed between the glasses employed in the above experiments, so that the reflected rays may traverse them in passing from one surface to the other, it will be found that, under certain circumstances, the image of the candle will remain visible; in other words, the light will be *depolarised* in passing through the crystallized medium. Common glass is generally incapable of depolarising the ray, but it acquires the depolarising power when submitted to pressure, or heated, or when it has been heated and very suddenly cooled; the influence of its particles upon those of light becoming then analogous to crystallized bodies.

That a sunbeam, in passing through a dense medium, and especially through a triangular prism of glass, gives rise to a series of brilliant tints similar to those of the rainbow, was known in the earliest ages, but it required the sagacity of Newton to develop the cause of the phenomenon. He proved that light consists of rays differing from each other in their relative refrangibilities; and, guided by their colour, considered their number as seven: red, orange, yellow, green, blue, indigo, and violet. If the prismatic colours, or *spectrum*, be divided into 360 equal parts, the red rays will occupy 45 of these parts, the orange 27, the yellow 48, the green 60, the blue 60, the indigo 40, and the violet 80. Of these rays, the red being least refrangible, fall nearest that spot which they would have passed to, had they not been refracted; while the violet rays, being most refrangible, are thrown to the greatest distance; the intermediate rays possess mean degrees of refrangibility.

These differently-coloured rays are not susceptible of further decomposition, by any number of refractions, but when they are collected into a focus they re-produce white light. Upon these phenomena is founded the Newtonian *theory of colours*, which supposes them to depend upon the absorption of all rays, excepting those of the colour observed. Thus green bodies reflect the green rays and absorb the others. All the rays are reflected by white bodies, and absorbed by those which are black.

According to the experiments of Herschel, the greatest illuminating power of the prismatic spectrum is found in the bright yellow or pale green rays. The orange possess it in a higher degree than the red rays; and from the full deep green it decreases towards the violet. (*Phil. Trans.* 1800.)

Section II. Of the Operation of Radiant Matter in producing Heat.

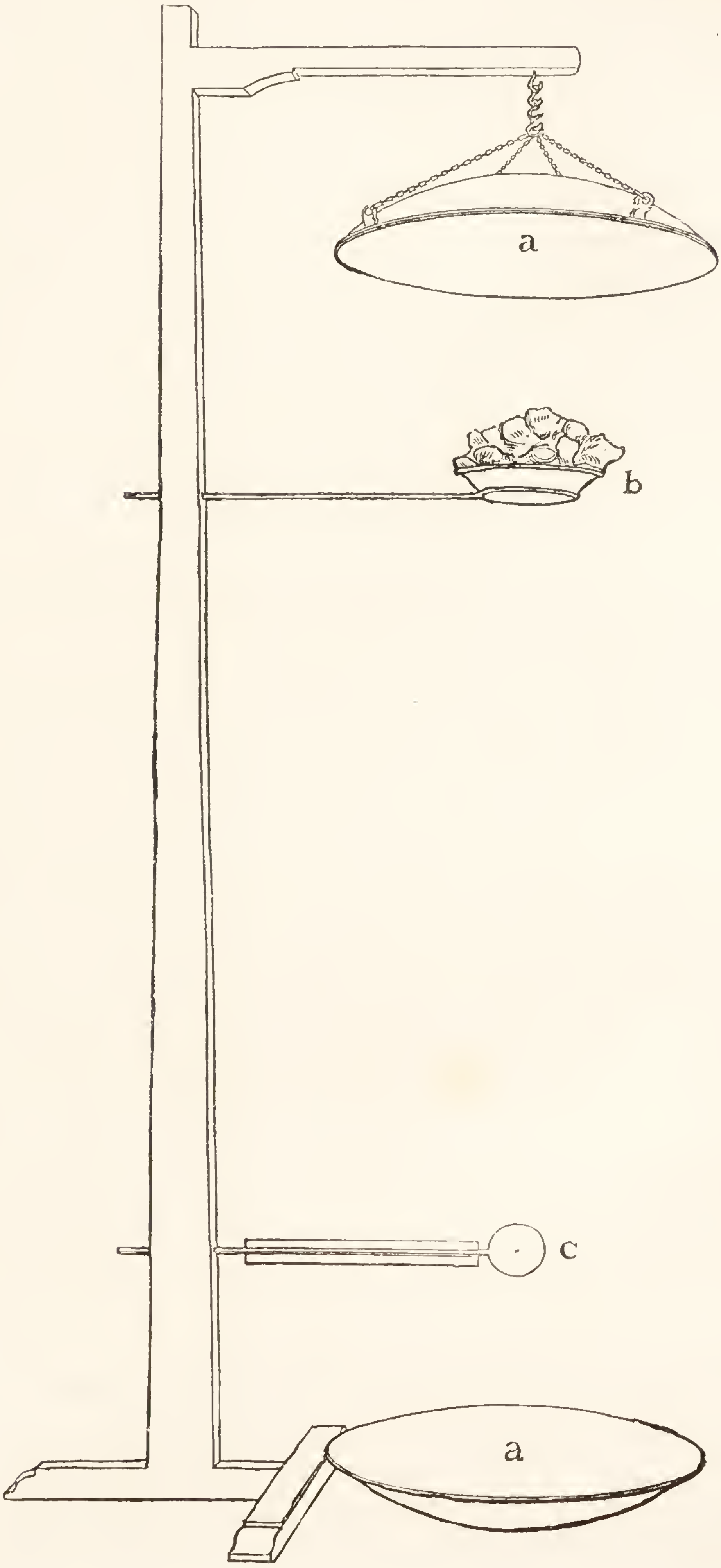
If a solar beam be refracted by a prism, and the coloured image received upon a sheet of paper, it will be found, on moving the hand gently through it, that there is an evident increase of temperature towards the red ray. This fact seems to have been first noticed by Dr. Hutton (*Dissertation on Light and Heat*, p. 39); but it is to Herschel (*Phil. Trans.* 1800) that we are indebted for a full investigation of the subject. If the coloured rays be thrown successively upon delicate thermometers, it will be found, that if the heating power of the violet rays be considered = 16, that of the green rays will be = 26, and of the red = 55. These circumstances suggested the possibility of the heating power of the spectrum extending beyond the red ray; and on applying a thermometer just out of the red ray, and beyond the limits of the visible spectrum, this was found to be the case. A thermometer in the red ray rose 7° in ten minutes, but just beyond the red ray the rise was = 9°. It is evident, therefore, that, independent of the illuminating rays, there are others which produce increase of temperature, and these from their increase towards the red ray, and from the spot which they principally occupy in the refracted congeries, are possessed of less refrangibility than the visible rays.

Dr. Herschel's experiments were repeated, with nearly similar results, by Sir H. Englefield, in 1802, and by Mr. Berard, in 1813, (Thomson's *Annals*, ii. 163,) who found the maximum of heat to exist just at the extremity of the red ray. Others, however, have asserted that it is in the red ray; and M. Seebeck has shown that the precise point depends upon the prism used in the experiment: with one of flint glass the greatest heat was found, as described by Herschel; but with one of crown glass, it was in the verge of the red ray. With a glass prism containing water, the greatest heating power was concentrated with the illuminating power, in the yellow ray. These facts seem to indicate a difference in the power of different prisms in refracting the calorific rays.

That these calorific rays are susceptible of refraction and reflection, is proved by the intense heat produced when the solar rays are concentrated into a focus by a lens, or by a concave mirror.

Radiation of Terrestrial Heat. — The radiant matter, emitted by terrestrial bodies at high temperatures, agrees in many of its properties with that constituting the solar rays, but in others it presents apparent peculiarities: the investigation of this subject constitutes a beautiful department of philosophic inquiry.

The effect we perceive in approaching a fire chiefly results from radiation, and is little connected with the immediate conducting power of the air; and if a concave *metallic* mirror be



held opposite the fire, a heating and luminous focus will be obtained. The affections of terrestrial radiant matter are best demonstrated by employing two concave mirrors of planished tin or plated copper, placed at a distance of about ten feet asunder. (Pictet, *Essais de Physique.*) Under these circumstances, when a thermometer is in the focus of one of the mirrors, it will be found sensible to the effects of a heated body placed in the focus of the opposed mirror; and that the effect is produced by reflection, and not by mere direct radiation, is proved, either by drawing the thermometer out of the focus towards the opposed mirror, or by placing a screen between the thermometer and its mirror, when diminution of temperature is in either case indicated. In these experiments the differential thermometer is most advantageously employed, and the mirrors may be placed opposite each other on the ground, or vertically suspended, as in the woodcut, in the preceding page, where *a a* represent the mirrors, *b* a pan of hot charcoal, *c* an air thermometer.

If the flame of a candle be placed in the focus of one mirror, a heating and luminous focus is obtained from the other: but if a plate of glass be now interposed between the two mirrors, the rays of heat are arrested, while those of light, freely passing through the glass, are collected, as usual, in the opposite focus. It has hence been concluded, that there is a difference between solar and terrestrial heat; the rays of the former passing through glass without heating it; while the rays of the latter are stopped by glass, and it becomes hot when opposed to them.—(Scheele's *Experiments on Air and Fire.*) But the rays of burning bodies may in many instances be shewn to pass through glass with great facility; thus, a bright gas flame affords a heating as well as a luminous focus, when its rays are concentrated by a double convex lens, upon the bulb of an air thermometer.—Brande, *Phil. Trans.* 1820, p. 27.

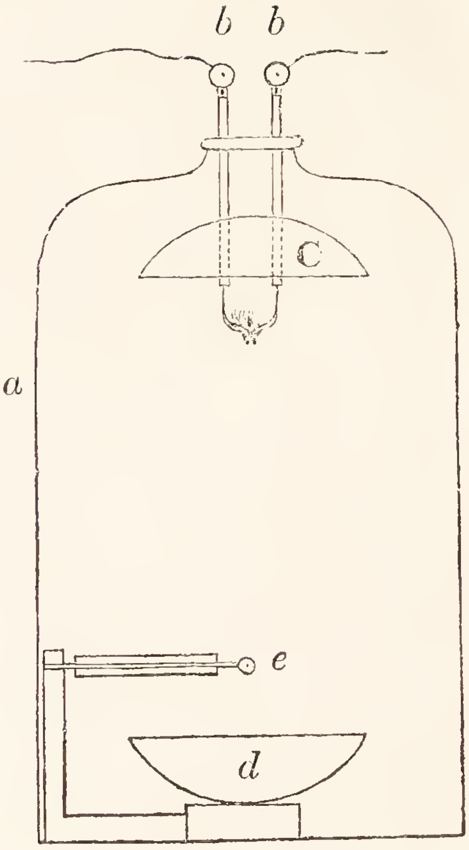
In these experiments upon the radiation of terrestrial heat, the temperature excited by the radiant matter appears always relative to that of the heated or radiating body; and if we assume that all bodies are constantly throwing off radiant matter, the effects of temperature which it produces, when condensed or collected into a focus by a concave mirror, will bear a relation to the source; for the particles may be conceived to move with such velocity as not to be affected by circumjacent bodies, or by the circumambient air. Thus, white-hot iron produces a greater effect upon the focal thermometer than that which is only red-hot, and red-hot iron causes a greater effect than hot water: a body of the same temperature as the thermometer causes no change in it; but cold bodies produce an effect of cold, because the particles which they radiate, when stopped by impinging upon the thermometer-bulb, are of a lower temperature.

Radiation has by some been accounted for upon the idea of the heated body producing undulations in the air, something analogous to the waves excited by sonorous bodies; but the different phenomena of prismatic refraction and of solar and terrestrial radiation are not satisfactorily explained upon such an hypothesis.

Newton endeavoured to explain the different refrangibility of the rays of light, by supposing them composed of particles of different sizes; and adopting this hypothesis, we should say, that the particles of red light were largest, those of violet light smallest. The heating rays would consist of particles yet larger than those producing colour; and the smallest particles, or most attenuated radiant matter, would be that which produces certain chemical changes. — (Newton's *Optics.*) Upon this hypothesis, too, it would appear that the particles of terrestrial heat are of so large a size as to be partially arrested in their progress by glass and other transparent bodies, which allow a free passage to solar radiant matter.

Newton has also put the query, "Whether light and common matter are not convertible into each other?" And, if we consider sensible heat in bodies to depend upon vibrations of their particles, a certain intensity of vibrations may send off particles into free space; and particles moving rapidly in right lines, may, in losing their own motion, communicate a vibratory motion to the particles of terrestrial bodies.— Davy's *Elements*, p. 215.

Radiation goes on in all elastic media, and in the Torricellian and air-pump vacuum, as may be shown by igniting charcoal by means of the Voltaic battery, placed in the focus of a small mirror confined in the exhausted receiver of the air-pump. Sir H. Davy found, that the receiver being exhausted to $\frac{1}{120}$, the effect upon the thermometer in the opposite focus was nearly three times as great as when the air was in its natural state of condensation. *a* is the receiver, *b b* the insulated wires connected with the voltaic apparatus igniting the charcoal in the focus of the upper mirror C. In the focus of the lower mirror *d* is the thermometer *e*.



It has long been known, in regard to solar rays, that their heating effect depends much upon the colour of the surfaces upon which they impinge, and that black and dark bodies are more heated than those which are white or of light tints, circumstances dependent upon absorption and reflection.

Professor Leslie has shewn, that the phenomena of terrestrial radiation are connected with the nature of the radiating surface; and that those surfaces which are the best radiators of this heat, are also gifted with the greatest absorbing power. —Leslie *on Heat.*

Unmetallic and unpolished surfaces are the best radiators, and also the best receivers of radiant heat; while polished metallic substances are the worst radiators, and have the lowest absorbing powers. In the experiments with the metallic mirrors, the whole nearly of the heat is reflected, and the mirror itself does not become warm: but if it be coated with any unpolished, and especially unmetallic coating, as with paper, or paint, the reflection is then scarcely perceptible, and the mirror becomes hot from the absorption of the radiant matter.

In Professor Leslie's experiments it was found, that a clean metallic surface produced an effect = 12 upon the thermometer. When covered with a thin coat of glue, its radiating power was so far increased as to produce an effect = 80; and, on covering it with lamp-black, it became = 100.

In these cases of radiation, the *colour* of the surface does not interfere, and the different effects must be referred to the mechanical structure of the radiating surface. White paper and lamp-black produce nearly the same effects; and paper, coloured blue, red, yellow, and green, does not differ in radiating power from that which is white, provided the colour produces no change of texture in the paper.

The connexion of the receptive with the radiating power is made obvious by coating the bulbs of thermometers with different substances. Thus, the effect of radiant heat upon a thermometer bulb covered with a thin coating of lamp-black being = 100; when the bulb is covered with silver leaf the effect is only = 12. MM. Dulong and Petit, in their valuable *Memoir on Heat*, which gained the prize medal of the Academy of Sciences for 1818, have detailed a variety of important facts upon the subject of the radiation of surfaces.

Upon the principle of the absorption of the solar rays by blackened surfaces, Mr. Leslie has constructed a *photometer*. It is merely a very delicate and small differential thermometer, inclosed in a thin and pellucid glass tube. One of the bulbs is of black glass, which, when the instrument is suddenly exposed to light, becoming warmer than the clear bulb, indicates the effect by the depression of the fluid.—(Leslie *on Heat*, p. 424.) A differential thermometer, containing the vapour of ether, may also, in certain experiments, be advantageously used as a *Photometric Thermometer*.—Brande, *Phil. Trans.* 1820.

It is obvious, from the above-mentioned facts, that all vessels intended to retain heat, should be clean and metallic, for polished metallic surfaces have very low radiating powers; whereas those vessels which are either to receive, or to radiate, should be blackened upon their surfaces. The knowledge of these properties is economically applicable in a variety of cases.

From the facts which have now been stated, in conjunction with those described in the section on Heat, it is obvious, that when a body is allowed to cool in the air, or in other fluid, that its excess of heat will be carried off partly by radiation, and partly by currents established in the fluid, the absolute conducting power of which must also be taken into the account. Supposing, however, a body to be placed in a perfect vacuum, its heat would be dissipated by radiation only: to determine, under these circumstances, the rate of cooling, an elaborate inquiry has been undertaken by MM. Dulong and Petit (*Ann. de Chim. et Phys.* vii.); but the details rather belong to physical than chemical science. It appears that bodies cool about twice as fast in the air as in vacuum: Dr. Franklin conceived that a body requiring five minutes in vacuo, would cool through the same number of degrees in air in two minutes. Count Rumford gives the proportions of five minutes and three. But it must be remembered that the rate of cooling will much depend upon the relative temperature of the body, and that it will lose unequal quantities of heat in equal times, forming, according to Newton, a decreasing geometrical progression. Thus, supposing the temperature of a body to be 1000° above the surrounding medium, in the first minute it will lose $\frac{9}{10}$ of its heat, or 900°; in the second, $\frac{9}{10}$ of the remainder, or 90°; and in the third, $\frac{9}{10}$ of 10°, or 9°. This law of cooling, however, though tolerably correct at low temperatures, becomes liable to much error at high ones, the error increasing as the temperature augments. In relation to this subject, two general laws have been deduced from the experiments of Dulong and Petit, for the details of which we must refer to their elaborate memoir; viz., *where a body cools in a vacuum, surrounded by a medium, of which the temperature is constant, the velocity of cooling, from excess of temperature in arithmetical progression, increases as the terms of a geometrical progression, diminished by a certain quantity.*

The law of cooling in vacuo being determined, it is easy to separate from the total cooling of a substance immersed in air or other medium, the portion of effect due to the contact of the medium. For this, it is only required to subtract from the observed velocities of cooling, those which would take place if the body were in vacuo. From such experimental comparisons the following law has been deduced:—

The velocity of cooling of a body, owing to the sole contact of a gas, depends for the same excess of temperature, on the density and temperature of the gas; but this dependence is such, that the velocity of cooling remains the same, if the density *and temperature of the gas change in such a way that the elasticity remains constant.*

Phenomena of Dew.—The dependance of the phenomena of dew upon the radiating powers of different surfaces has been happily investigated by Dr. Wells (*Essay on Dew*). It was generally supposed that a diminution of the temperature of the air occasioned it to precipitate moisture upon the earth; but Dr. Wells's experiments have shown, that, previous to the deposition of dew, the earth's surface, upon which it forms, becomes colder than the circumambient air, in consequence of its loss of heat absorbed during the day by radiation. Wool, swandown, and other good radiators, when exposed after sunset, have their temperatures diminished from 10 to 15° below that of the air, so also has the grass; but this great decrease of heat, or increase of radiation, only goes on to this extent when the sky is clear and serene; clouds diminish or altogether prevent it; so do coverings of any kind which are intercepted between the radiating body and the sky, though they be so placed as not, in any other way, to interfere with the temperature of the surface. Gravel walks radiate much less than grass plats; hence a piece of wool acquires much less weight from the precipitation of moisture when placed upon gravel than when lying upon grass: grass is a good radiator, and therefore becomes considerably more bedewed than a surface of metal; and if a piece of glass partially coated with clean tinfoil be exposed to a clear nocturnal sky, the dew will first be deposited upon the parts remotest from the metal.

It has been stated that the aspect of the heavens materially influences terrestrial radiation; of this, Dr. Wells's experiments have furnished some excellent illustrations: if the night, at first clear, becomes cloudy, the temperature of the grass always rises, independent of any changes of calmness and nearly so of change of atmospheric temperature; upon one such night the grass, after having been 12° colder than the air, became only 2° colder, the temperature of the atmosphere remaining stationary; and on another occasion, the temperature of the grass rose 15°, while the air only sustained an increase of 3½°.

From these, and other observations, it is obvious that the grass becomes an indicator of hygrometric moisture in the air, and that the temperature requisite for the formation of dew will be inversely as the quantity of vapour in the surrounding atmosphere. It is curious to observe the different appearances of vegetables on a dewy morning, depending upon their relative radiating powers. On the 24th of September, 1821, at seven in the morning, the sky nearly cloudless, the temperature of the air was 55° ; that of a grass plat 38°; the leaves of a sunflower 36° ; those of a cabbage 34° ; while those of a large hairy-leaved geranium were 30°, and covered with hoar frost. (On the application of these principles to horticulture, see Mr. Daniell's paper in the *Horticultural Transactions*, and in his Essays.)

Where the temperature of the earth has become, by radiation, considerably lower than that of the air, and the difference sometimes exceeds 30°, it is obvious that the lower strata of the air will be colder than the upper; on such occasions, the atmosphere, between 200 and 300 feet above the earth's surface, is sometimes 10° warmer than upon it or 5 or 6 feet above it; and as tranquillity of the air is essential to the utmost cooling by radiation, hollows, and places apparently protected, will suffer more from fogs and dews than high and exposed situations; and grass and low shrubs, more than trees and bushes.

The production of ice in Bengal, as described by Mr. Williams (*Phil. Trans.*, lxxxiii.), is chiefly referable to the high radiating powers of the dry straw which is strewed in the inclosures containing the water in shallow dishes. Calm and serene nights are most favourable to this operation, and it is necessary that the straw should be dry, for when wetted the production of cold is prevented; a circumstance which shows that evaporation is not the cause of the diminished temperature.

Section III. OF THE INFLUENCE OF RADIANT MATTER IN PRODUCING CHEMICAL CHANGES.

RADIANT matter possesses considerable influence over the chemical energies of bodies. If a mixture of equal volumes of the gases called chlorine and hydrogen be exposed in a dark room, they slowly combine, and produce muriatic acid gas; but, if exposed to the direct rays of the sun, the combination is very rapid, and often accompanied by an explosion.

Chlorine and carbonic oxide have scarcely any tendency to combine, even at high temperatures, when light is excluded, but exposed to the solar rays they enter into chemical union. Chlorine has little action upon water, unless exposed to light; and, in that case, the water, which consists of oxygen and hydrogen, is decomposed. The hydrogen unites with the chlorine to produce muriatic acid, and the oxygen is evolved in a gaseous form.

These, and numerous other similar cases which might be adduced, show that radiant matter influences the chemical energies of bodies, independent of its heating powers. Scheele (*Experiments on Air and Fire*, p. 78, &c.) was the first who entered upon this curious investigation; and many important facts connected with it have been more lately ascertained by Ritter, Wollaston, and Davy. Scheele threw the prismatic spectrum upon a sheet of paper, moistened with a solution of nitrate of silver, a salt quickly decomposed by the agency of light. In the blue and violet rays the silver was soon reduced, producing a blackness upon the paper, but in the red ray scarcely any similar effect was observed. Wollaston and Ritter discovered that these chemical changes were most rapidly effected in the space which bounds the violet ray, and which is out of the visible spectrum.

It has been thus ascertained, that the solar beams are refrangible into three distinct kinds of rays; the *calorific*, or heating rays; the *luminous*, or *colorific* rays, which produce vision and colour; the *decomposing* rays, or those which have a tendency to interfere with the chemical constitution of bodies.

In the prismatic spectrum these three sets of rays are imperfectly separated, and arranged according to their respective refrangibilities. The heating rays are the least refrangible; the colorific rays are possessed of more refrangibility; and the decomposing, or, as some have called them, the *deoxidizing rays*, are the most refrangible.

Sir H. Davy has observed, that certain metallic oxides, when exposed to the violet extremity of the prismatic spectrum, undergo a change similar to that which would have been produced by exposure to a current of hydrogen; and that, when exposed to the red rays, they acquire a tendency to absorb oxygen. (*Elements of Chemical Philosophy.*) In such general facts, he traces an analogy between the effects of the solar beam, and the agencies of electricity. In the Voltaic circuit, the maximum of heat is at the positive pole, where the power of combining with oxygen is also given to bodies; the agency of rendering bodies inflammable is exerted at the opposite surface; and similar chemical effects are produced by negative electricity, and by the most refrangible rays; and by positive electricity, and the rays which are least refrangible.

Morichini ascertained that part of the prismatic spectrum is capable of exciting the magnetic influence, and that a needle exposed to the violet rays acquires polarity (*Ann. de Chim. et Phys.* iii. 323; *Quart. Journ.* v. 138; *Thomson's Annals*, xii. 1): this points out a further analogy between the agencies of light and electricity. This subject has been more recently elucidated by the experiments of Mrs. Somerville, who rendered needles magnetic by exposure to the blue rays. The green rays produce the same effect in a less degree, but the orange and red rays are inactive.—*Phil. Trans.*, 1826, 132.

In nature the influence of the solar rays is very complex, and the growth, colour, flavour, and even the forms of many vegetables, are much dependent upon them. This is seen in many plants which are protected from the sun's rays; celery and endive are thus cultivated with the view of rendering them palatable; and plants which are made to grow in a room imperfectly illuminated, always bend towards the apertures by which the sun's rays enter. The changes, too, which vegetables effect upon the circumambient atmosphere are influenced by the same cause.

In the animal creation, brilliancy of colour and gaudy plumage belong to the tropical climates; more sombrous tints distinguish the polar inhabitants; and dull colours characterize nocturnal animals, and those who chiefly abide below the surface.

Section IV. Of the Phenomena exhibited by Luminous and Incandescent Bodies, and of the Nature and Properties of Flame.

When bodies are rendered luminous by considerable elevation of temperature, the light which they emit often appears dependent upon the heat to which they are subjected; and the common terms *red-hot* and *white-hot* are used to designate those appearances. There are, however, certain bodies which, at high temperatures, are remarkable for the quantity and extreme brilliancy of their light, independent of actual combustion; this is the case with several of the earths, but more especially with lime, a small ball of which about ¼ inch diameter being ignited in the flame of alcohol urged by oxygen gas, emits light, having about thirty-seven times the intensity of an Argand's lamp burner. (*Lieutenant Drummond on the means of facilitating the Observations of distant Stations in Geodætical Operations. Phil. Trans.* 1826, p. 324.)

There are many substances which, when heated to a certain point below incandescence, become luminous without undergoing combustion, and such bodies are said to be *phosphorescent.* The temperatures which they require for this purpose are various; it generally commences at about 400°, and may be said to terminate at the lowest visible redness. Some varieties of phosphate of lime, of fluor spar, of bituminous carbonate of lime, of marble, and sand, and certain salts, are the most remarkable bodies of this description. (Wedgwood, *Phil. Trans*. v. 82.) Their luminous property may be best exhibited by scattering them in coarse powder upon an iron plate heated nearly to redness. Oil, wax, spermaceti, and butter, when nearly boiling, are also luminous. The most extended experiments on phosphorescence of minerals are those of Dr. Brewster. (Ed. *Phil. Journ.* i.)

When a Leyden phial is discharged upon certain substances they become durably phosphorescent; this is the case with loaf-sugar, quartz, and several other mineral and saline bodies. —*Skrimshire in Nich. Jour.* xv., xvi., xix.

Another class of phosphorescent bodies have been termed *solar phosphori*, from becoming luminous when removed into a dark room after having been exposed to the sunshine. Of this description are Canton's, Baldwin's, and the Bolognian phosphorus. Canton's phosphorus is prepared thus:—Calcine oyster-shells in the open fire for half an hour, then select the whitest and largest pieces and mix them with one-third their weight of flowers of sulphur, pack the mixture closely into a covered crucible, and heat it to redness for an hour. When the whole has cooled, select the whitest pieces for use.—*Phil. Trans.* v. 58. See also some observations upon the subject by M. Osann, quoted in the *Quarterly Journal, N.S.*, iv. 204.

Baldwin's phosphorus is prepared by heating nitrate of lime to a dull red heat, so as to form it into a compact mass; and the Bolognian phosphorus, discovered by Vincenzio Cascariolo, a shoemaker, of Bologna, is made by reducing compact sulphate of baryta to a fine powder, which is formed into cakes with mucilage, and these are heated to redness.—Aikin's *Dictionary*, Art. Phosphori.

Mr. B. Wilson has also made a variety of curious experiments on solar phosphori; and he has discovered the simplest and most effectual of these bodies, which may be obtained by closely observing the following directions:—Take the most flaming coals off a brisk fire, and throw in some thick oyster-shells; then replace the coals, and calcine them for an hour; remove them carefully, and, when cold, it will be found that after exposing them for a few minutes to the light, they will glow in the dark with most of the prismatic colours—Wilson *on Phosphori, p.* 20. The phenomena of the solar phosphori have also been elaborately examined by M. Heinrich (*Bib. Univ.* xv. 247).

A third set of bodies, belonging to this class, are those which are *spontaneously phosphorescent*. Such are, especially, the flesh of salt-water fish just before it putrefies, and decayed wood. The *glow-worm* and the *lantern fly*, the shell-fish called *pholas*, the *medusa phosphorea*, and various other mollusca, are also luminous when alive; and the *hundred-legged worm*, and some other worms and insects shine brilliantly when irritated.

Dr. Mac Culloch, in his work on the Western Islands of Scotland, and in a paper published in the *Quarterly Journal* (xi., 249), has detailed some valuable facts respecting that beautiful appearance of light in sea-water, so well known to those who are conversant with the ocean during the darkness of night; he has shown that the sea is often crowded with worms and insects nearly invisible, and that its luminous property not only bears a relation to the existence and number of these at any time, but may generally be traced to the individuals by which it is caused. One of these luminous animals, described by Captain Home, is figured in the *Quarterly Journal, N. S.* vol. iv., p. 383.

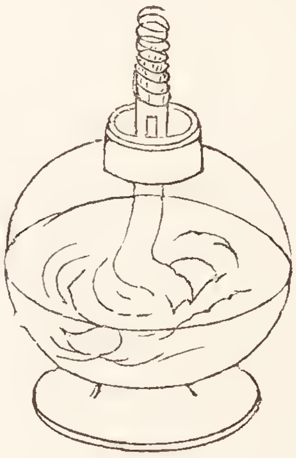
It appears, from the experiments of Canton and of Dr. Hulme, (*Phil. Trans.* vols. lix. xc. and xci.) that sea-fish become luminous in about twelve hours after death, that it increases till putrefaction is evident, and that it then decreases. Immersion in sea-water does not affect this luminous matter, on the contrary, the brine is itself rendered luminous: but it is extinguished by pure water, and by a variety of substances which act chemically upon the animal matter.

Percussion and friction are often attended by the evolution of light, as when flint pebbles, pieces of sugar, and other substances, are struck or rubbed together.

From experiments in which air has been intensely heated, it has been concluded that gaseous matter is incapable of becoming luminous; for, though the temperature of air be such as to render solid bodies white hot, it does not itself become visible. (Wedgwood, *Phil. Trans.* 1792.) Flame, however, may in general be regarded as luminous gaseous matter. Hydrogen gas, probably, furnishes the purest form of flame which can be exhibited; for the flames of bodies which emit much light, derive that power from solid matter which is intensely ignited and diffused through them, and which, in ordinary flames, as of gas, tallow, wax, oil, &c. consists of finely-divided charcoal.

The intensity of the heat of flames which are but little luminous, as of hydrogen gas, spirit of wine, &c., may be shown by introducing into them some fine platinum wire, which is instantly rendered white hot in those parts where the combustion is most perfect. It is even intensely ignited in the current of air above the flame, as may be shown by holding a piece of platinum-wire over the chimney of an Argand lamp fed with spirit of wine; the high temperature of this current is also exhibited by the common expedient of lighting paper by holding it in the heated air which rushes out of a common lamp glass.

The high temperature of flame is further proved by certain cases of combustion without flame. Thus, if a heated wire of platinum be introduced into any inflammable or explosive mixture, it will become *ignited*, and continue so till the gas is consumed; but *inflammation* will, in most cases, only take place when the wire becomes white hot. This experiment is easily made by pouring a small quantity of ether into the bottom of a beer glass, and holding a piece of heated platinum wire a little above its surface; the wire becomes red hot, but does not inflame the vapour of the ether till it acquires an intense white heat.



The same fact is exhibited by putting a small coil of patinum wire round the wick of a spirit lamp, which, when heated, becomes red hot, and continues so, as long as the vapour of the spirit is supplied, the heat never becoming sufficiently intense to produce its inflammation.

Such being the nature of flame, it is obvious, that if we *cool* it by any means, we must at the same time *extinguish* it. This may be effected by causing it to pass through fine wire gauze, which is an excellent conductor and radiator of heat, and consequently possessed of great cooling power. If a piece of fine brass or iron wire-gauze be brought down upon the flame of a candle, or what answers better, upon an inflamed jet of coal gas, it will, as it were, cut the flame in half. That the cooled gaseous matter passes through, may be shewn by again lighting it upon the upper surface.

The power, therefore, of a metallic tissue thus to extinguish flame, will depend upon the heat required to produce the combustion, as compared with that acquired by the tissue; and the flame of the most inflammable substances, and of those that produce most heat in combustion, will pass through a metallic tissue that will interrupt the flame of less inflammable substances, or those that produce little heat in combustion ; so that different flames will pass through at different degrees of temperature.

The discovery of these facts, respecting the nature and properties of flame, led Sir H. Davy to apply them to the construction of the *Miner's safety lamp*, which will be explained under the article *Carburetted hydrogen gas.*

The phenomena exhibited by phosphorescent and incandescent bodies, and in the process of combustion, have sometimes been explained, upon the idea that the light and heat evolved were previously in combination with the substances, and that they are afterwards merely emitted, in consequence of decomposition; and that the solar phosphori absorb light and again give it out unchanged. But it appears more probable that any particles violently repelled into space may become radiant matter, than that it should consist of a *specific* substance : thus, mechanical action, and chemical changes, may each tend to the emission of radiant matter; and incandescence will result when the vibrations which heat occasions among the particles of bodies are of such violence as to cause their repulsion into space.

The intensity of the light of flames, or their relative illuminating powers, may be judged of by the intensity of the shadows which they produce. (*Rumford*, *Phil. Trans.*) For this purpose place the flames a few inches asunder, and at the distance of a few feet from a screen of white paper. On holding a small card near the screen two shadows will be projected on it, the darker one by the interception of the brighter light, and the lighter shadow by the interception of the duller light. Bring the fainter light nearer to the card, or remove the brighter one further from it, till both shadows acquire the same intensity : then measure the distances of the two lights from the screen, square them, and you have the ratio of illumination. Thus, if a gas light and a candle stand at the distances of ten feet and four feet respectively when their shadows are equally intense, we have 10^2 and 4^2, or 100 and 16, or 6.25, and 1 for their relative quantities of light.—*Ure's Dict.*, Art. LIGHT.

CHAPTER III.

OF THE SIMPLE ELECTRO-NEGATIVE SUPPORTERS OF COMBUSTION.

The substances belonging to this class are characterized by possessing very energetic powers of combination in respect to the simple inflammable bodies, and they are each of them capable of producing acids, whence they may also be termed *acidifying* principles. When their compounds are submitted to electro-chemical decomposition, these elements are attracted by the positive surface; hence their natural or inherent electrical states may be considered as negative.

These acidifying, electro-negative supporters of combustion, are five in number :

1. Oxygen.
2. Chlorine.
3. Iodine.
4. Bromine.
5. Fluorine.

The following examples will serve to give some idea of the principles of nomenclature generally adopted in chemistry, in respect to the compounds of these and other bodies. The above bodies in entering into combination with each other, and with the bodies described in Chapters IV. and V., produce two classes of compounds. Those which are not acid, are usually distinguished by the termination *ide*, as *oxide* of chlorine, *chloride* of sulphur, *iodide* of iron, *bromide* of phosphorus, *fluoride* of calcium, &c. ; and where more than one compound of this kind is produced, the terminations *ous* and *ic* are used to designate the relative proportions of the supporters of combustion. Thus nitrogen forms two oxides ; that containing the smallest proportion of oxygen is the *nitrous* oxide, that containing the largest the *nitric* oxide. The acid compounds are similarly designated, as *nitrous* and *nitric* acid ; *sulphurous* and *sulphuric* acid ; and where there are intermediate compounds, the term *hypo* is occasionally added to the acid next above it in point of oxidizement. Thus, *hyposulphuric acid* signifies an acid compound intermediate between the sulphurous and sulphuric acids ; *hypophosphorous* acid, an acid containing less oxygen than the phosphorous acid.

The different combinations of the metals with oxygen are perhaps best distinguished by prefixing to the word *oxide* the first syllable of the Greek ordinal numerals, as originally proposed by Dr. Thomson. Thus the *protoxide* of a metal will denote the compound containing a minimum of oxygen, or the first oxide which the metal is capable of forming ; *deutoxide* will denote the second oxide of a metal, &c. ; and when a metal is combined with the largest possible quantity of oxygen, the compound, if not acid, may be called *peroxide.* The same rule applies to the *chlorides, iodides,* &c.

The acids terminating in *ous* produce compounds in which the termination *ite* is used ; while those ending in *ic* form compounds in which the ending *ate* is used. Thus the combination of sulphurous acid and potassa, is a *sulphite* of potassa ; that of sulphuric acid and potassa, a *sulphate* of potassa, &c.

When the same acid combines with more than one oxide of the same metal, the first syllable of the Greek ordinal numeral is in that case applied to the acid : thus, the *protosulphate* and *persulphate* of iron, signify the combinations of sulphuric acid with the protoxide and peroxide of iron. The term *oxysulphate* is occasionally used to designate the latter compound, and in the same sense we speak of *oxynitrates, oxyphosphates,* &c., but the former mode of designation is less equivocal.

The compounds of the simple inflammable bodies described in Chapter IV., with each other, and with those in Chapter V., are commonly designated by the termination *uret,* as *sulphuret* of phosphorus, *phosphuret* of carbon, *carburet* of iron, &c.

The terms *bi sulphuret, bi phosphuret,* &c., applied to compounds, imply that they contain twice the quantity of sulphur, phosphorus, &c., existing in the respective sulphuret and phosphuret.

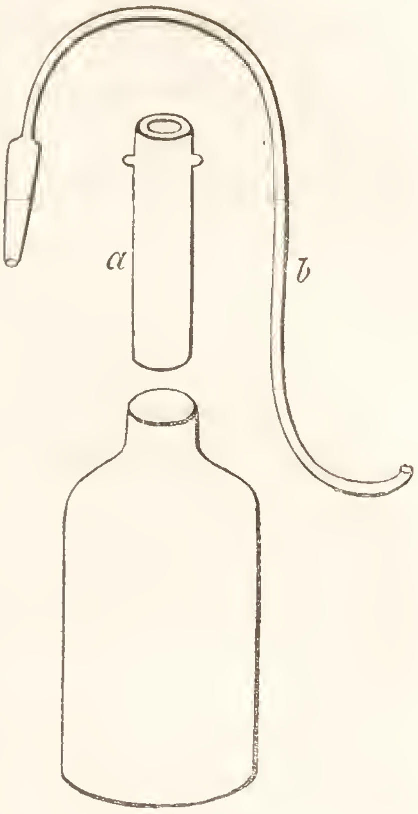
In regard to salts containing the same acid and base in different proportions, and formerly distinguished into *neutral, super,* and *sub* salts, the same method of nomenclature is applied. The neutral salt containing one proportional of base and one of acid is simply designated by its generic name, as *sulphate of potassa*, for instance. Where one proportional of base is combined with two or more of acid, forming a super-salt, a Latin numeral is prefixed, so as to indicate its composition; thus, we have *bin*oxalate and *quadr*oxalate of potassa. Where two proportionals of base are united to one of acid, the term *sub* has generally been used; but Dr. Thomson proposes to distinguish them by the Greek numerals *dis*, *tris*, &c. Thus the *di*nitrate of lead consists of one proportional of nitric acid combined with two of oxide of lead.

Section I. Of Oxygen.

This elementary gaseous body was discovered by Priestley on the 1st of August, 1774; it may be obtained by a variety of processes, of which those only in common use will be noticed here, and the others adverted to in their proper places.

To obtain it in the purest state proceed as follows: introduce into a small glass retort (as shown at D in the wood-cut, p. 136) about 100 grains of the salt called *chlorate of potassa*, and gradually heat it over a gentle charcoal fire, or by means of a large spirit lamp, having previously placed the beak of the retort under the shelf of the hydro-pneumatic apparatus. Suffer the common air of the retort to escape, and when the salt fuses and appears to boil, collect the oxygen which it then gives out, in proper vessels, taking care so to adjust the heat as to cause the gradual decomposition of the salt, and occasion the air bubbles to follow each other with moderate rapidity. Towards the end of the process the heat may be so far increased as to render the bottom of the retort red-hot, being careful, however, not to fuse it, and when gas ceases to be evolved, withdraw the retort and put it aside: it is seldom fit for a second operation. From 100 grains of the chlorate, we may expect to obtain nearly 100 cubic inches of gas.

Another substance from which oxygen may be obtained, at a much cheaper rate than from the former, is *black oxide of manganese*, but the gas is never very pure, and the quantity produced from a given weight of the oxide is very variable. A pound should yield from 40 to 50 pint measures. The oxide of

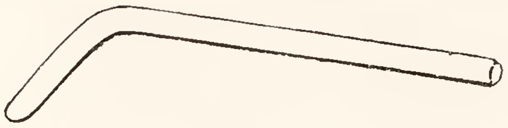


manganese should be powdered, dried, and introduced into an iron gas bottle, which may be about four-fifths filled with it, and placed with its proper connecting tubes, in a convenient furnace or fire-place. These gas bottles are most conveniently made of wrought iron, of the shape annexed, their capacity being between a pint and a quart. The connecting tube, *a*, should be of iron, and fitted by grinding into the neck of the bottle; and the delivery tube, *b*, which may be of pewter, as it is convenient to have it flexible, should be similarly ground into the upper end of the canister. When these bottles are used, the joints may be made tight by the previous application of a little grease.

When the bottle containing the oxide of manganese becomes red hot, the oxygen begins to pass off by the pewter tube, which must be so bent as to pass under the shelf of the water apparatus. Collect some of the gas in a small jar or tube, and test it by introducing into it a small piece of wood which has been inflamed and blown out, so that the end remains only glowing; if the gas be sufficiently pure, it will immediately burst out into flame and burn vehemently: the oxygen may then be collected for use, either in bottles, jars, gasholders, or gasometers, as required. When the gas ceases to be evolved, the retort must be removed from the fire; and, when cold, emptied of its contents, which will be found to be an oxide of manganese, of a brown colour, containing of course less oxygen than the black, and not further decomposable by heat alone.

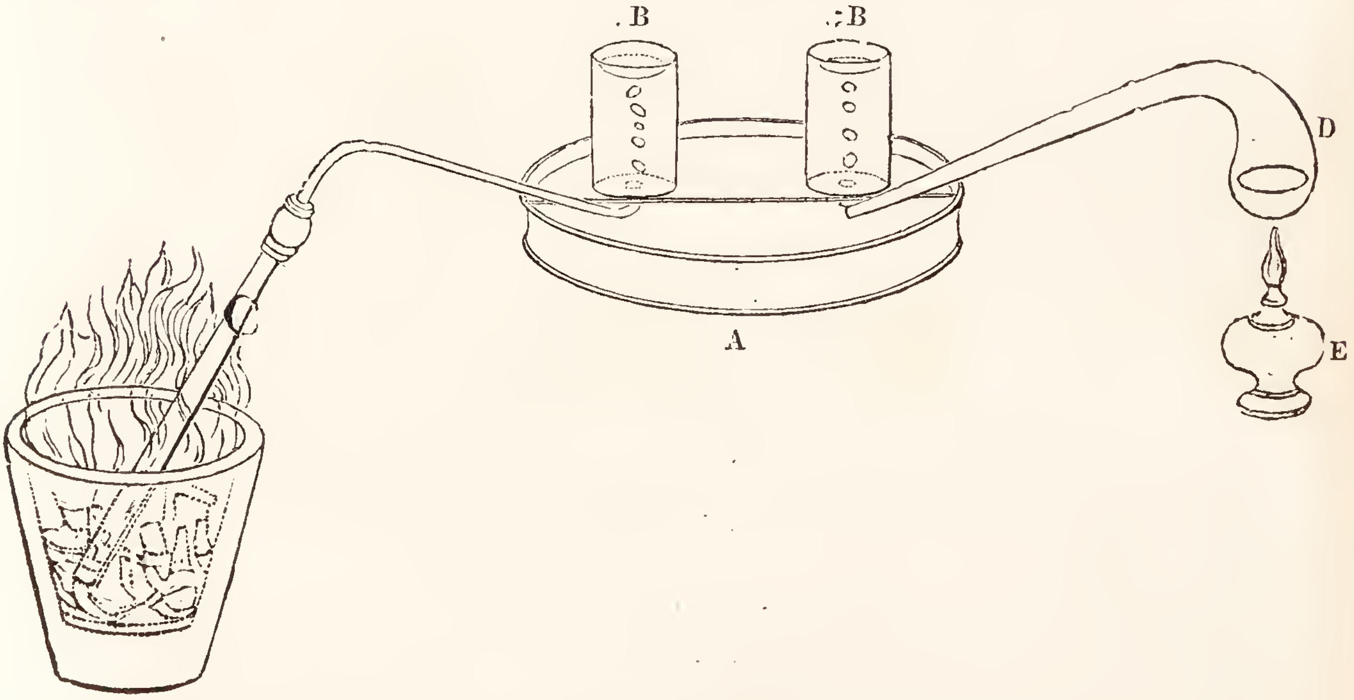
Oxygen gas may also be obtained from a mixture of black oxide of manganese and sulphuric acid in such proportions as to be about the thickness of cream; this mixture is put into a glass retort, and heated over an Argand lamp, the gas being collected in the usual way. This method is sometimes convenient where an iron retort cannot be procured; but it is not economical, and the ingredients are apt to harden in the retort, which is often broken in attempting to cleanse it.

If perfectly pure oxygen be required, it must be obtained from chlorate of potassa and collected over mercury; and as it is often wanted in the experimental laboratory in very small quantities only, a small retort made out of a piece of glass tube, bent into the annexed form, may be conveniently used.



In all cases where gases are to be obtained by processes similar to the preceding, common glass, or earthenware *retorts*, may be used; or, where a red heat is required, they may be made of wrought iron, either in the same form, or in that of a bottle, as described above, or of a tube, or other convenient shape.

The *hydro-pneumatic apparatus* consists of a japanned iron or copper vessel *, of different shape and size, according to the particular purposes for which it is intended, and containing a shelf perforated with holes through which the gas may pass into inverted vessels properly placed for its reception. In this wood-cut, A is the hydro-pneumatic trough; B B, inverted glasses for the reception of gas; C, a wrought iron tube placed in a pan of charcoal for the evolution of gases requiring a red heat; D, a retort heated by the spirit lamp E.



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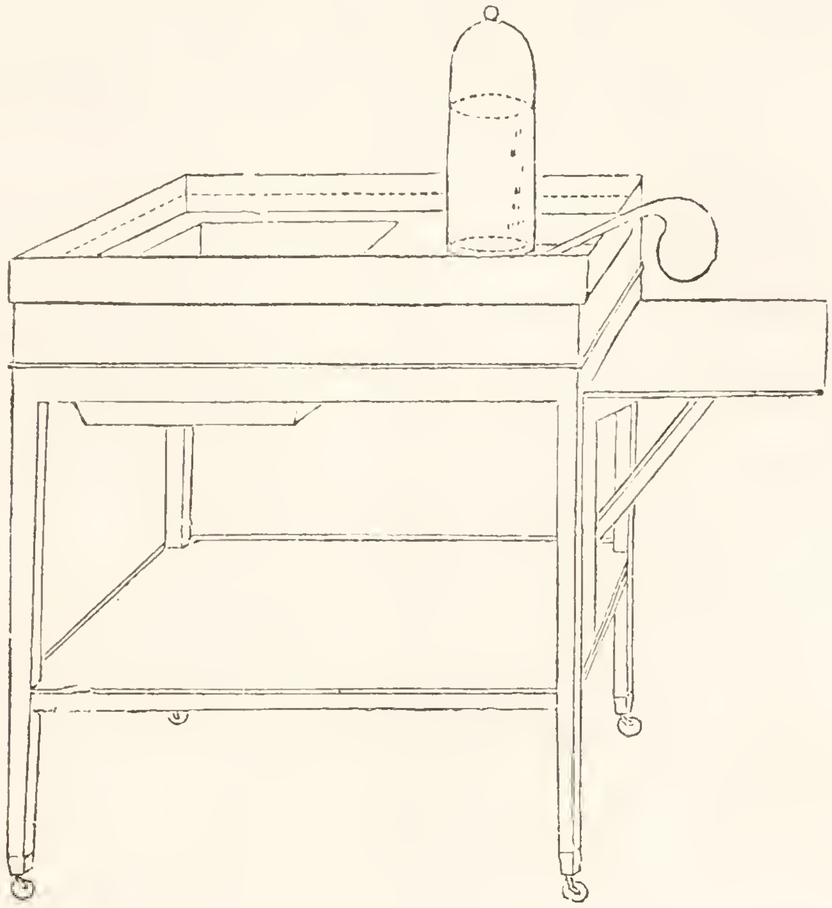
* In the construction of these vessels, and of airholders, and gasometers, copper is, upon the whole, greatly preferable to japanned or tinned iron: at the outset it is more expensive, but it is infinitely more durable, less liable to leak, and sells as old copper when worn out.

For experiments, in which larger vessels are employed for collecting or transferring gases, the annexed form of the apparatus is most convenient.



Vessels of various forms are employed for receiving, retaining, and measuring gases. Where it is intended to introduce different substances into the gas, they may be of the form represented in figure 1, drawn into a neck with a glass-stopper at top, and open at bottom. Some of these should be graduated into cubic inches, and supplied with a stop-cock, as in figure 2. For measuring small quantities of gases, tubes are

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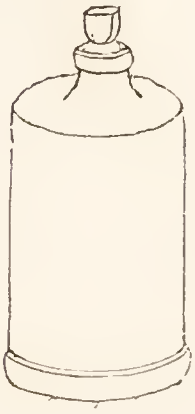

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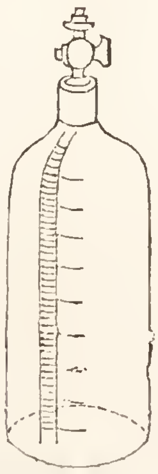

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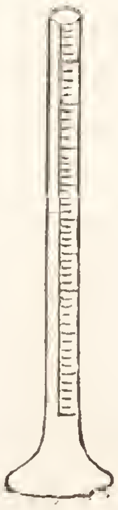
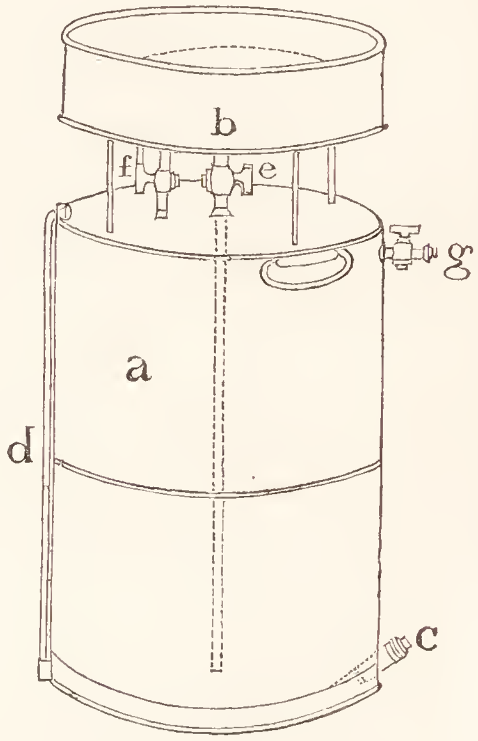


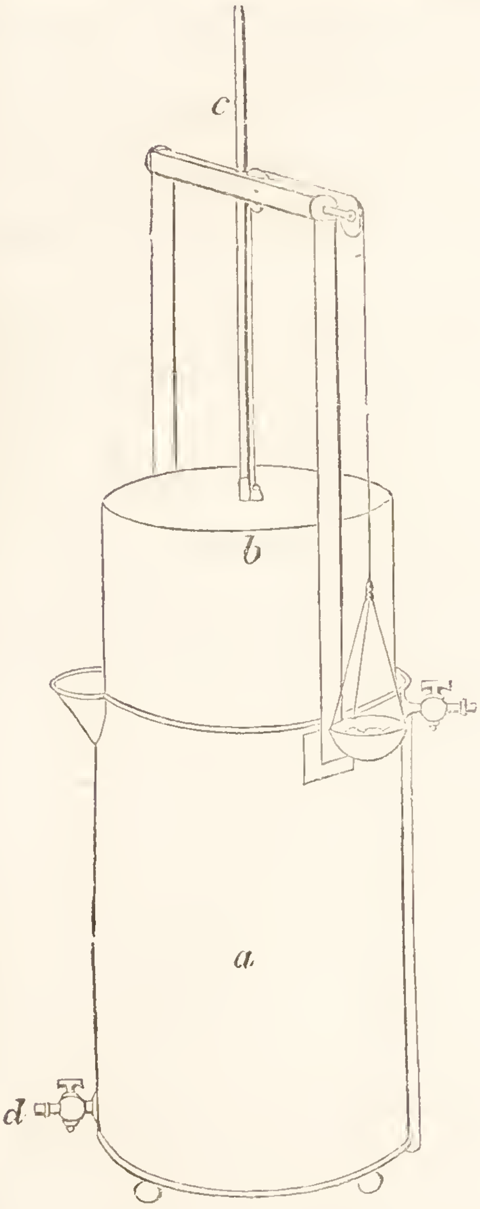
employed, some of which should be divided into 100 equal parts, other in tenths and hundredths of a cubical inch. Figures 3, 4.

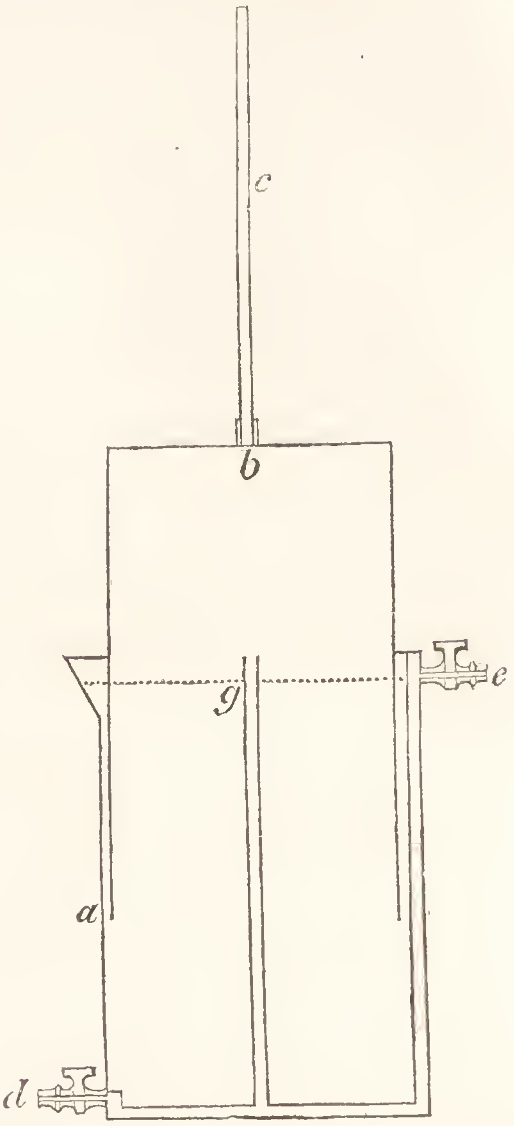
Where large quantities of gases are required to be collected and preserved, we employ *gasholders* and *gasometers*. The annexed cut represents Mr. Pepys's improved gasholder, made of japanned iron, or what is preferable, of copper. It consists of a body or reservoir *a*, which may hold from two to six or eight gallons: *b*, is a cistern from which issue two tubes, supplied with stop-cocks, one entering the reservoir at its upper part, the other continued, as shown by the dotted lines, to near the bottom: *c*, is a short tube issuing fron the bottom of the reservoir, and capable of being accurately closed by a screw. *d*, is a glass tube communicating at both ends with the body of the gasholder. When it is intended to fill this apparatus with gas, the tube *c* is closed, and the stop-cocks, *e*, *f*, are opened; water is then poured into the cistern, which, running down the long tube *e*, forces the air out through the shorter one *f*. The reservoir being thus filled, the stop-cocks are closed, and the aperture *c*, is opened, into which the beak of the retort, or tube, whence the gas issues, is introduced, and bubbling up, displaces the water which runs out at the same opening. When it is seen in the tube *d*, that nearly the whole of the water is displaced, the aperture is closed, and the vessel is now filled with gas, which may either be drawn off into receivers, placed in the cistern *b*, by opening the two stop-cocks *e*, *f*; or by closing the stop-cock *f*, and opening *g*, it may be propelled into bladders, or transferred in any convenient way by an attached tube.



A view and section of the *gasometer* are shown in the following sketches:—

It may be made of japanned iron or copper. *a a*, is the outer circular vessel, or pail, to the sides of which the tubes *d*, *e*, (each fitted with a stop-cock externally) are soldered. The tube *d* penetrates at the bottom of the pail, and proceeds

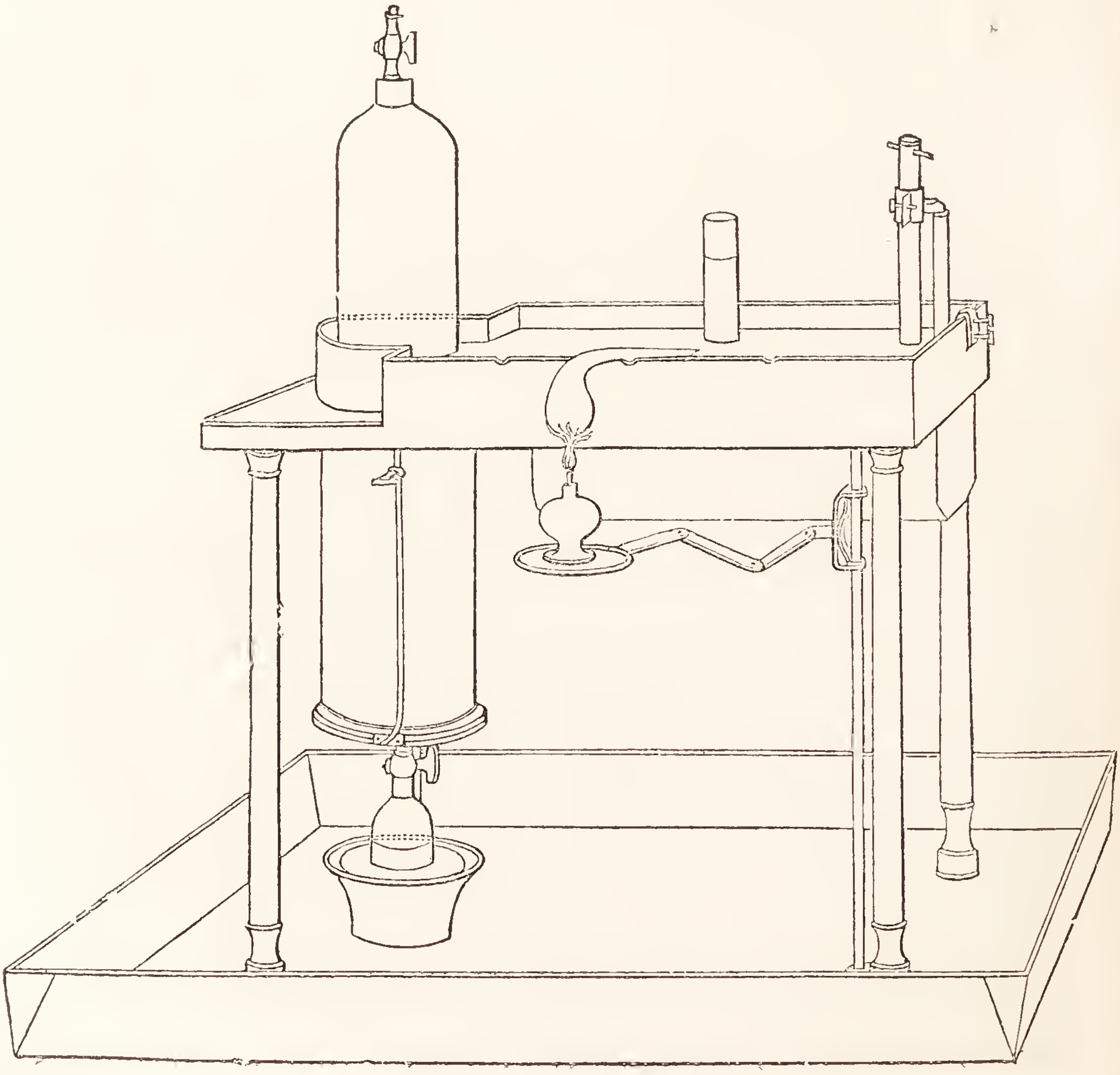




to the centre, where it joins the tube *e*, which enters the top of the pail, and proceeds downwards; and from the place of junction, the upright tube *g* rises through the middle of the pail a little above the level of its upper rim. The vessel *b* is a cylinder open only at the bottom, and of less diameter than the pail in which it is inverted, and can move up and down freely. This cylinder has a solid stem *c*, which passes through a hole in the cross-bar of the frame fixed to the top of the pail; it serves to steady the cylinder, and to indicate the quantity of the inclosed gas; the weight of the cylinder is counterpoised in any convenient way.

To use this gasometer, first let the cylinder fall to the bottom of the pail, and fill the latter with water; then shut the cock *e*, and open *d*, and connect with it the tube which conveys the gas from the retort, gasholder, or other vessel; or, if more convenient, shut *d*, and convey the gas through *e*. The gas rises, and gradually lifts up the cylinder, which must be properly balanced: and when sufficiently filled, the cock, by which it entered, must be closed. The gas may now be drawn off at either of the stop-cocks, by a tube passing into the water-trough, or it may be propelled through a blow-pipe, or otherwise employed.

Those gases which are absorbed by water, may, in most instances, be collected over mercury. The best form of the *Mercurio-pneumatic apparatus*, is that contrived by Mr. Newman (*Quarterly Journal*, vol. i. p. 185.) It is a trough of cast-iron, supported by brass or iron legs, and having a small gasometer at one end. It is placed in a japanned iron tray to collect the scattered mercury, as shown in the woodcut.



Oxygen gas is insipid, colourless, and inodorous; it is permanently elastic, under all known pressures and temperatures. Its specific gravity, compared with air, is as 1.111 to 1.000; compared with hydrogen, its specific gravity is = 16, hydrogen being = 1. At mean temperature and pressure, 100 cubic inches weigh 33.8 grains. Its refractive power, in regard to light, is less than that of any known body: compared in this respect with atmospheric air, it is as 0.86161 to 1000. According to De la Roche and Berard, its specific heat, compared with an equal *volume* of air, is 0.9765, and with an equal *weight* of air, = 0.8848, that of air being = 1.000.

When powerfully compressed by the sudden depression of a piston in a glass tube, oxygen becomes momentarily luminous, a property which has not been observed in any gaseous body, except such as contain oxygen, and which may therefore be considered as one of its characteristics. It is absorbed in very small quantity only by water; it does not alter the colour of litmus, nor does it render lime water turbid.

It is a powerful supporter of respiration. A small animal, confined in oxygen gas, lives thrice as long as when confined in the same bulk of common air; it has therefore been called *vital air;* but we are not thence to conclude that it is fit for the support of life: on the contrary, an animal made to breathe oxygen for any length of time, falls a sacrifice to excess of arterial action, and after death the blood in the veins is found as florid as that in the arteries.

A lighted taper, introduced into this gas, is very rapidly consumed, with intense ignition and enlargement of the flame. Sulphur, which burns in the air with a small blue flame, soon has its flame enlarged when immersed into a jar of oxygen, and blazes with a beautiful purple colour. It dissolves as it were in the oxygen, and converts it into sulphurous acid gas, which is absorbed by water. Phosphorus, when inflamed in the atmosphere, burns with a bright light, but in oxygen the eye can scarcely bear its brilliancy, and the heat which it evolves is very intense. A piece not larger than a pea should be used in the experiment. The oxygen combines with the phosphorus, and forms a quantity of white flaky matter, very soluble and deliquescent, which is chiefly phosphoric acid. This, and the combustion of sulphur, may be best performed by placing them in a small copper basin, attached to a wire annexed to a spare stopper, or passing through a cork which fits the neck of the air jar. The disadvantage of a cork is, that it is sometimes apt itself to take fire and crack the jar.

One of the most brilliant instances of combustion in oxygen is the burning of iron wire. For this purpose the jar should be capacious, and placed over water in a common soup plate; the oxygen should be very pure. A piece of thickish annealed iron wire should be attached to the spare stopper, and loosely wound round with repeated twists of harpsichord wire, so as to form a tangled coil, nearly of the thickness of one's finger; the sulphur tip of a match should then be broken off, and affixed to the end of it; when this is inflamed, and the coil immersed into the jar of gas, vivid combustion soon ensues: it throws off brilliant sparks, and partly fuses into globules of oxide iron, which fall through the water, and lie for some time red hot upon the plate, which they often fuse at the point of contact. A piece of annealed watch spring may also be used for this experiment.

In all these cases of combustion in oxygen gas, the sudden expansions which take place are apt to endanger the jar, which should therefore be held by the hand, so as to allow the occasional escape of a little of the gas, and at the same time prevent the jarring of the bell glass upon the plate beneath.

The results of the above, and other cases of combustion in oxygen, will be more fully detailed and explained hereafter. —(*See* Carbon, Sulphur, Phosphorus, and Iron.) It may suffice to state at present, that in all cases of combustion in oxygen, the combustible and the oxygen combine, and the product of combustion consequently manifests an increase in weight proportionate to the quantity of oxygen with which it has united. Acids, alkalies, earths, and oxides will be found to be the result of these combinations, which are either effected slowly, and without the evolution of heat and light; or very rapidly, with the phenomena of combustion and flame; or with intermediate rapidity, exciting considerable elevation of temperature, and often even a red heat, though without flame, as in some cases which have been already cited (p. 103.)

The phenomena of combustion were referred by Stahl and his associates to a peculiar principle which they called *phlogiston;* it was supposed to exist in all combustibles, and combustion was said to depend upon its separation: but this explanation was absurdly at variance with the well-known fact, that bodies during combustion increase in weight.

After the discovery of oxygen gas, it was adopted by Lavoisier as the universal supporter of combustion. The basis of the gas was supposed to unite to the combustible, and the heat and light which it before contained in the gaseous state, were said to be evolved in the form of flame. But in this case, several requisites are not fulfilled; the light depends upon the combustible, and not upon the quantity of oxygen consumed; and there are very numerous instances of combustion in which oxygen, instead of being solidified, becomes gaseous during the operation; and, lastly, in others, no oxygen whatever is present. Combustion, therefore, cannot be regarded as dependent upon any peculiar principle or form of matter, but must be considered as a general result of intense chemical action. It may be connected with the electrical energies of bodies; for all bodies which powerfully act upon each other, are in the opposite electrical states of positive and negative; and the evolution of heat and light may depend upon the annihilation of these opposite states, which happens whenever they combine.—See the *Prefatory History of Chemistry*, and the Section on Electricity, p. 90.

Oxygen is more abundantly diffused throughout nature than any of the other elementary bodies; it forms eight-ninths of the weight of water, about one-fifth of the weight of the atmosphere, and a large relative proportion of the earthy and mineral bodies which form the solid matter of the globe. It also forms, with scarcely one exception, an element of the various products of organized bodies both in the animal and vegetable creation.

Section II. Of Chlorine.

To obtain this gas, a mixture of equal weights of black oxide of manganese and muriatic acid may be heated over a lamp in a glass retort: Chlorine is soon copiously evolved, and may be conveniently collected over warm water; it is absorbed by cold water, and cannot, therefore, be long retained over that fluid; so that it should be received into bottles provided with ground stoppers: when these are full, the stopper, previously greased a little, should be introduced under water, care being taken to exclude the water from their interiors. In consequence of the deleterious nature of chlorine, its escape into the atmosphere of the laboratory should be prevented, by collecting the first portions which come over mixed with the common air of the retort, in a jar, which may afterwards be carried away into the open air, or placed under a chimney. The gas may be preserved for use when it passes over of its full colour, to judge of which, the neck of the retort should be kept clean; it should not be more than half filled with the materials, which are otherwise apt to boil over, and soil the water in the trough.

It may also be procured from a mixture of 8 parts of common salt, 3 of pulverized black oxide of manganese, 4 of water, and 5 of sulphuric acid: or the proportions recommended by Thenard may be used; viz., 4 parts of common salt, 1 part of oxide of manganese, 2 of sulphuric acid, and 2 of water. The theory of its production in these cases will be explained afterwards.—See *Muriatic Acid*, and *Sulphate of Soda.*

Chlorine was discovered by Scheele in 1774. Consistently with his theoretical notions of its nature, he called it *dephlogisticated muriatic acid.*—*Mem. Acad. Stockholm,* 1774, p. 94. The term *oxymuriatic acid* was afterwards applied to it by the French chemists.—*Berthollet, Jour. de Phys.*, p. 325.

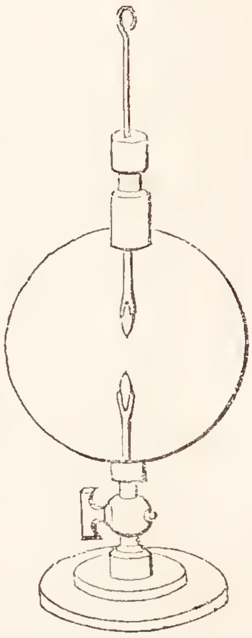
The more appropriate term chlorine (from χλωρος), which merely designates its colour, was given to it by Sir H. Davy, who, in 1810, published a masterly essay upon its nature, in the *Philosophical Transactions*, showing that, so far from containing loosely-combined oxygen, as the French chemists suspected, that element could not be shown to exist as one of its component parts; also that it contained no muriatic acid; that in all cases of the apparent evolution of oxygen and muriatic acid from chlorine, water was present, and was decomposed, and that in the present state of our knowledge, chlorine must be regarded as an undecompounded or elementary body.

Chlorine, at common temperatures and pressures, is a permanently elastic gaseous fluid; but, by subjecting it to a pressure equivalent to about 4 atmospheres, and at the temperature of 60°, Mr. Faraday succeeded in condensing it into the liquid form. It has a pungent and disagreeable smell, and is highly injurious when respired, even largely diluted with atmospheric air. Its colour is greenish yellow.

When perfectly dry, it suffers no change by exposure to the most intense cold, but in its ordinary state it contains aqueous vapour, which, at a temperature of 32°, is deposited in the form of a white crystalline compound, which liquefies, effervesces, and is again taken up by the gas, upon the application of heat.

This hydrate of chlorine may be best obtained by introducing into a clean bottle of the gas a little water, and keeping it for a few days in a dark place, at a temperature not exceeding 32°. It then forms prismatic and acicular crystals, having a specific gravity of about 1.2, and composed, according to Mr. Faraday, of 27.7 chlorine and 72.3 water, or about 1 proportional of chlorine to 10 of water: added to alcohol, these crystals occasion an elevation of temperature of about 10°, and generate muriatic acid and ether. They decompose solutions of ammoniacal salts with the evolution of nitrogen, muriatic acid and chloride of nitrogen being formed. (*Quarterly Journal*, xv.) Chlorine was the first of the gases supposed to be permanently elastic, which Mr. Faraday succeeded in condensing into the liquid state: he effected this by putting some of the dried hydrate of chlorine into a small bent tube, hermetically sealed, and applying a gentle heat; a yellow vapour formed, which condensed in the cold part of the tube into two distinct fluids, the uppermost and lightest of which was mere aqueous solution of chlorine, but the heavier was yellow, and separable by careful distillation; it did not solidify at 0°. If, when the fluids were separated, the tube was cut in the middle, the parts flew asunder as if with an explosion, the whole of the yellow portion disappeared, and there was a powerful atmosphere of chlorine produced. When the end of the tube in which the yellow fluid lay was broken under water, there was an immediate production of chlorine gas. The specific gravity of liquid chlorine is about 1.33. Its refractive power rather less than that of water.—*Phil. Trans.*, 1823, p. 160.

Chlorine is not altered by exposure to very high temperatures. By means of the following apparatus, Sir H. Davy exposed it to the continued action of charcoal intensely ignited by Voltaic electricity, without the smallest change in its properties.



A glass globe, of about four inches diameter, has at its upper part a sliding wire passing air-tight through a ground collar, to the lower end of which is attached a piece of well-burned charcoal: at bottom is a stop-cock supporting a brass pincers, in which is another pointed piece of charcoal; the globe is exhausted upon the air-pump, filled with chlorine, and the stop-cock and sliding wire attached to the extremities of the Voltaic apparatus; the charcoal points are then brought into contact by pushing down the upper wire, and they are thus retained as long as necessary in intense ignition.

The specific gravity of chlorine, compared with hydrogen, is as 36 to 1; 100 cubic inches weigh 76.25 grains. Compared with air, its specific gravity is 2.500 to 1.000.

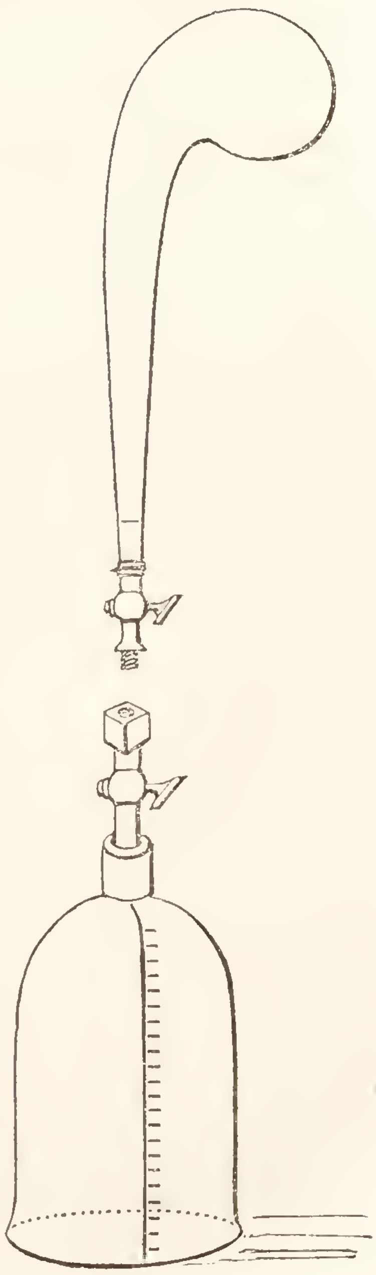
At the temperature of 60°, water dissolves two volumes of chlorine. The solution is of a pale yellow colour, has an astringent, nauseous taste, and destroys vegetable colours: hence its use in bleaching: though the gas itself, when perfectly free from moisture, has scarcely any action upon them.

When this aqueous solution of chlorine is exposed to the direct rays of the sun, oxygen is evolved in consequence of the decomposition of the water, the hydrogen of which unites to the chlorine, and forms muriatic acid. Placed in the electric current of the Voltaic pile, the hydrogen of the water is evolved at the negative pole, and the chlorine, with the oxygen of the water, are evolved at the positive pole.

Chlorine, and its aqueous solution, are powerful antiseptics and destroyers of contagious and infectious matter, and of bad odours. This property depends upon the power which chlorine has of decomposing those nocuous compounds, and resolving them into others which are harmless. For the purposes of fumigation, chlorine liberated from manganese and muriatic acid, or manganese salt and sulphuric acid, may be diffused through the atmosphere of the infected chambers, or the infected goods may be exposed to it. In the same way the offensive odour of dead bodies may be mitigated by sprinkling them with solution of chlorine.—Faraday, *Quarterly Journal*, xviii. p. 92.—See *Carbonate of Soda*, *Chloride of Lime &c.*

When a burning taper is immersed in a jar of chlorine, the brilliancy of the flame is much impaired; it becomes red, throws off much charcoal, and is soon extinguished.

Many bodies, such as phosphorus and several of the metals, are spontaneously ignited by chlorine, and burn in it with much brilliancy. In these cases, binary compounds result, some of which, like those of oxygen, are possessed of acid properties: others are not acid; and such compounds with oxygen being called *oxides*, those which chlorine forms may be termed *chlorides*. Brass or copper leaf, and powdered antimony, serve well to show the intense action of chlorine upon certain metals. When introduced into the gas, they enter into immediate combustion, and chlorides of copper and of antimony are formed. The most elegant way of making these experiments consists in introducing the phosphorus or copper leaf into a retort (see the woodcut), mounted with a stop-cock, and exhausted upon the air-pump; it is then screwed into the cap of an air jar of chlorine also mounted with a stop-cock, and standing over water in the pneumatic trough. Upon opening the cocks,



the gas rushes from the jar into the retort, and the phosphorus or copper leaf immediately burn. With any quantity of copper leaf the heat is generally so sudden and intense as to crack the retort. It may here be observed, that in consequence of their irregular thickness and form, retorts are frequently broken by the air's pressure whilst exhausting; so that it is safe to cover them with a cloth during the process, to prevent the splinters being thrown about.

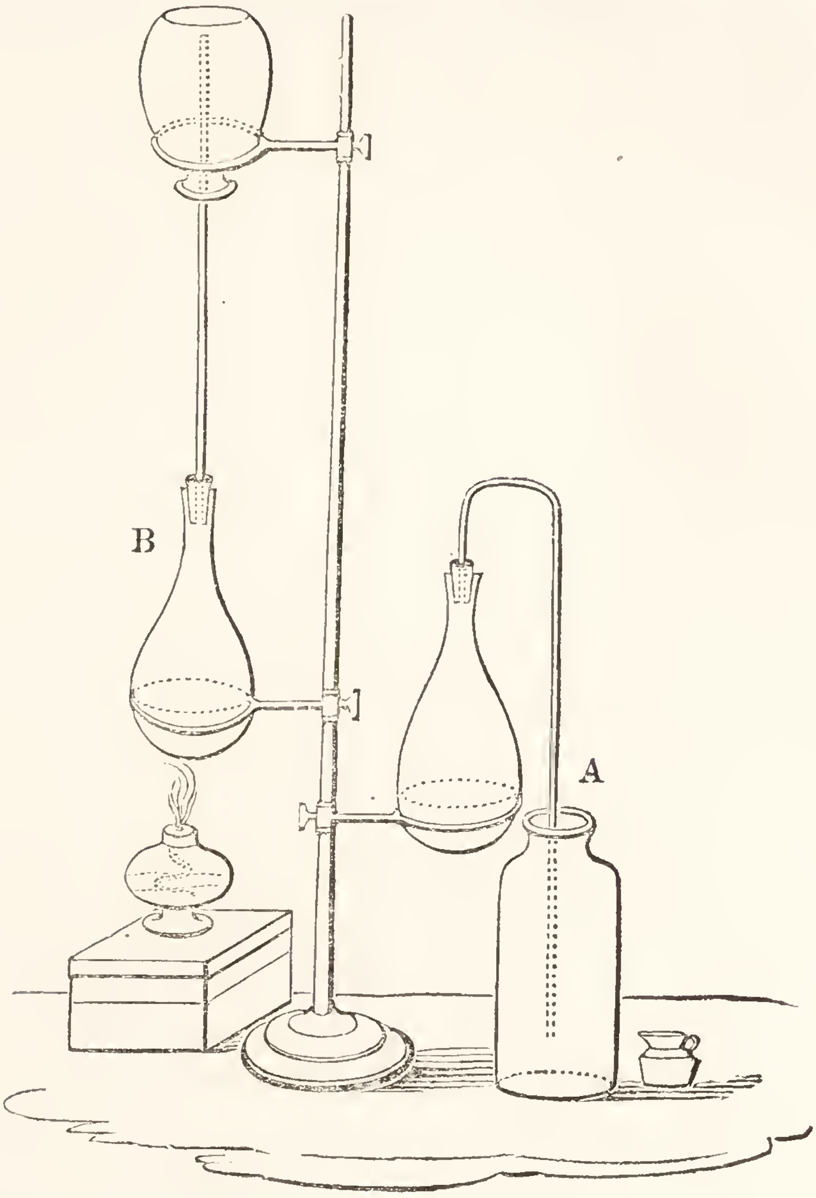
Chlorine and Oxygen.—Chlorine and oxygen unite in four proportions, forming two oxides and two acids.

In these compounds the elements are held together by feeble affinity, so that they are difficultly formed, and easily decomposed. They do not occur in nature, and cannot be obtained by the direct union of their components; for mixtures of chlorine and oxygen exert no mutual action.

The protoxide	of chlorine	consists of	36	parts of chlorine	+ 8	oxygen
The peroxide	,,	,,	36	,,	+ 32	,,
Chloric acid		,,	36	,,	+ 40	,,
Perchloric acid		,,	36	,,	+ 56	,,

Protoxide of Chlorine was discovered by Sir H. Davy (*Phil. Trans.* 1811); and in consequence of its peculiar deep yellow-green colour, he gave it the name of *euchlorine.* It is easily absorbed by water, and must, therefore, be collected over mercury; but that metal gradually decomposes it, so that it cannot long be retained in its contact. Such gases, if they differ much in specific gravity from common air, may sometimes be collected sufficiently pure by placing the materials for producing them in a flask furnished with a tube of convenient length, and twice bent at right angles, so as to pass to the bottom of a clean stoppered phial: the disengaged gas, if heavier than the air, displaces it; and if, as in the present instance, coloured, it is easily seen when it is full: it must then be cautiously withdrawn, and stopped, and another phial put into its place: see the following wood-cut, A. If the gas thus to be collected is lighter considerably than the atmosphere, the tube from the flask may be straight, and pass up into an inverted phial, B. This method of collecting the oxides of chlorine is recommended and described by Professor Silliman. (*American Journal of Science*, vi. 165.)

To obtain protoxide of chlorine, introduce into a small re-



tort two parts of chlorate of potassa, and pour upon it one part of concentrated muriatic acid, previously diluted with one part of water; apply a *very gentle heat,* so as to occasion a moderate effervescence, and preserve the gas in small jars or tubes over mercury.

The odour of this gas has by some been compared to that of burned sugar, but it more resembles diluted chlorine; it is very pernicious to respiration, and is probably condensible into a liquid under pressure. Its specific gravity compared with air, is as 2.444 to 1.000.

Water dissolves ten volumes of this gas, and acquires its peculiar odour and a deep yellow colour; it destroys most vegetable colours, previously reddening some of the blues.

Its most remarkable character is the facility with which it is decomposed: when gently heated in the upper part of a small tube standing over mercury, a kind of explosion, attended by a flash of light, ensues, and the tube is projected to some distance; but if it be firmly held down in the mercury, the results of the decomposition are retained, and it is thus found that fifty volumes of the gas expand to sixty, forty of which are chlorine, and twenty oxygen. This gas sometimes explodes whilst it is collecting, or in being transferred from one vessel into another, or even by the heat of the hand, so that it should be cautiously dealt with and examined, and collected in small quantities only. Detonated with hydrogen in the proportion of five measures of the gas to eight of hydrogen, it gives rise to the production of water and muriatic acid. It is decomposed by all burning bodies, and their combustion continues as it would in a mixture of chlorine and oxygen in the above-mentioned proportions. A small piece of phosphorus let up into the gas instantly takes fire and absorbs it, burning with much brilliancy. It is not known to enter into any direct combination with other bodies.

Peroxide of Chlorine was discovered by Sir H. Davy in 1815 (*Phil. Trans.*, p. 214). It is obtained as follows:—about 50 grains of chlorate of potassa are moistened with a few drops of concentrated sulphuric acid, and rubbed together with a platinum spatula, till they incorporate and form a solid mass of an orange colour. This mass is to be introduced into a small glass retort, and gradually warmed in a water-bath, the temperature of which must be carefully kept below 212°, which may be managed by mixing alcohol with the water. A bright yellowish-green elastic fluid passes off, which is rapidly absorbed by water, but may be collected in small tubes over mercury. The colour of this gas is more brilliant than that of the protoxide, and its odour more aromatic, and unmixed with the smell of free chlorine. Its specific gravity compared with air is as 2.360 to 1.000: compared with hydrogen it is as 34 to 1, and 100 cubic inches should weigh at mean temperature and pressure 72.012 grains. When peroxide of chlorine is heated to a temperature somewhat below that of boiling water, it explodes with much violence and the evolution of a bright light. The result of this decomposition is, that two volumes of the gas are expanded into three, two of which are oxygen, and one chlorine; the relative weight, therefore, of its elements are 32 of oxygen (= 4 proportionals) and 36 of chlorine (= 1 proportional). It requires the same and even greater precautions, in preparing and transferring, as the former gas.

Its saturated aqueous solution is of a deep yellow colour, an astringent and corroding taste; and when applied to the tongue, leaves for a long time a very disagreeable sensation. It destroys vegetable colours.

Mr. Faraday condensed this gas by enclosing the mixture of chlorate of potassa and sulphuric acid in a sealed tube, and leaving them to act upon each other for twenty-four hours. In that time there had been much action; the mixture was of a dark reddish-brown, and the atmosphere within of a bright yellow colour. The mixture was then heated up to 100°, and the unoccupied end of the tube cooled to 0°: by degrees, the mixture lost its dark colour, and a very fluid ethereal-looking substance condensed. It was not miscible with a small portion of the sulphuric acid which lay beneath it; but when returned on to the mass of salt and acid, it was gradually absorbed, rendering the mixture of a much deeper colour even than itself. "The peroxide of chlorine thus obtained is a very fluid transparent substance of a deep yellow colour. A tube containing a portion of it in the clear end was opened at the opposite extremity; there was a rush of euchlorine vapour, but the salt plugged up the aperture: whilst clearing this away, the whole tube burst with a violent explosion."—*Phil. Trans.*, 1823, p. 194. Sir H. Davy found that, of the unmetallic combustible substances, phosphorus was the only one which spontaneously decomposed this gas: the phenomena were the same as with the protoxide of chlorine [*].

Chloric Acid.—In the compound which has been thus called by its discoverer, M. Gay Lussac (*Annales de Chimie*, tom. xci. p. 108), the relative proportions of chlorine and oxygen

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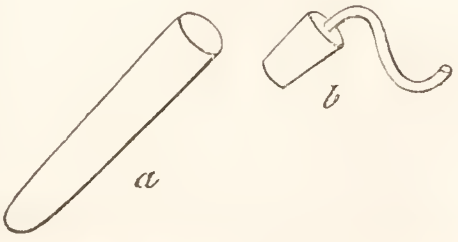
[*] In obtaining this gas in the Institution laboratory, we conveniently employ a small tube, sealed at one end, as a substitute for a retort, and fitted with a cork perforated by a small *S* tube, by which the gas is conveyed into the trough. I may take this opportunity of observing, that none but the best corks are fit for use in the laboratory; those in common use are never air-tight, and generally so hard as when thrust into a thin vessel to break it. The French corks are the best. *a* is the tube, which should be wrapped round with a little tow, in case of explosion, to prevent fragments being thrown about; *b* the cork, &c.



are to each other as 36 to 40 = 76: chloric acid cannot exist, independent of water or some base, and, therefore, may be compared to the *sulphuric* and some other acids, afterwards to be described.

Chloric acid may be prepared by passing a current of chlorine through a mixture of oxide of silver and water. Chloride of silver is produced, which is insoluble, and may be separated by filtration. The excess of chlorine, which the filtered liquor contains, is separable by heat, and the chloric acid dissolved in water remains. Chloric acid may also be obtained by adding dilute sulphuric acid to a solution of chlorate of baryta, as long as it occasions a precipitate. The baryta is thus separated in the form of an insoluble sulphate, and the chloric acid remains in aqueous solution. Care must be taken to add no more sulphuric acid than is requisite; for any excess contaminates the chloric acid. If the exact proportion has been used, the chloric acid is neither rendered turbid by dilute sulphuric acid nor by chlorate of baryta. If either of these occasion a precipitate, they must be carefully added till the effect ceases; the clear liquid may then be decanted or filtered off.

Chloric acid is a sour, colourless liquid, producing peculiar compounds, afterwards to be described. It forms no precipitate in any metallic solution. Its compounds are called *chlorates*. The most remarkable of them have been long known under the name of *Oxymuriates*. When chloric acid is distilled, it suffers a partial decomposition, and a portion of chlorine and oxygen are liberated. It is decomposed by muriatic and sulphurous acids, and by sulphuretted hydrogen; but those acids which are already saturated with oxygen do not act upon it. Its decomposition by muriatic acid is attended with the evolution of chlorine and the formation of water; by sulphurous acid, with the evolution of chlorine and the production of sulphuric acid; and by sulphuretted hydrogen with the separation of chlorine and sulphur, and the formation of water.

Perchloric, or *Oxychloric, Acid* was discovered by Count Stadion *: it is procured by distilling *perchlorate of potassa* with

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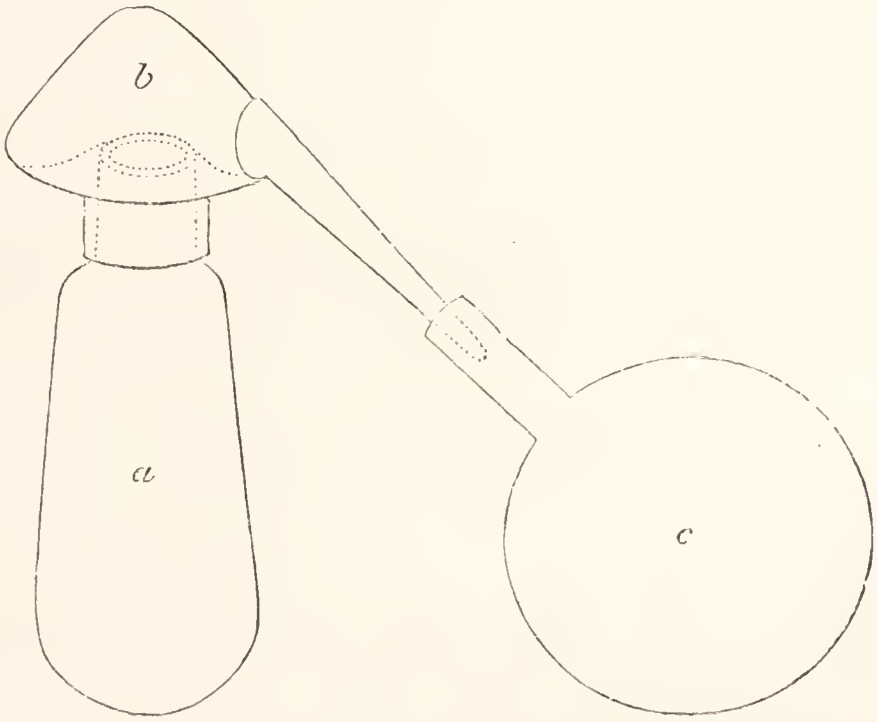
* Ann. de Chim. et Phys. viii.

its own weight of sulphuric acid, diluted with about a fourth part of water. At a temperature of about 280, white vapours pass off, which condense in the form of a colourless liquid. It consists of 36 chlorine + 56 oxygen*. It does not exist independent of water, or a base, and has been but imperfectly examined.

Section III. Of Iodine.

Iodine is procured by the following process: Lixiviate powdered *kelp* with cold water. Evaporate the lixivium till a pellicle forms, and set aside to crystallize. Evaporate the mother liquor to dryness, and pour upon the mass half its weight of sulphuric acid. Apply a gentle heat to this mixture in the flask *a* of the *alembic* shown in the annexed figure, of which *b* is the head or capital, having a tube issuing from it, and descending into the receiver *c*. Fumes of a violet colour arise, and condense in the form of opaque crystals, having a metallic lustre, which are to be washed out of the head of the alembic with a small quantity of water, and quickly dried on bibulous paper.



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* Gay Lussac, Ann. de Chim. et Phys. ix.

Iodine may likewise be obtained from soap-makers' *black ash* by a similar process: instead of evaporating the mother liquor to dryness, the quantity of iodine is sometimes greater when it is merely concentrated, mixed with excess of sulphuric acid, boiled, and filtered: the liquid is then mixed with its weight of powdered black oxide of manganese, and heated in an alembic, or flask with a tube attached to its neck, when the iodine sublimes as before.

According to Dr. Ure, iodine may be abundantly obtained from the brown residuary kelp liquor of the soap-boilers, by exposing it to a heat of about 230°, saturating it with sulphuric acid previously diluted with its bulk of water, and pouring the liquor, when cold, off the crystals which are deposited, and which are chiefly sulphate of soda. Filter the liquor, and to every 12 ounces, apothecaries' measure, add 1000 grains of black oxide of manganese in powder; put this mixture into a glass globe, or large matrass with a wide neck, over which a glass globe is inverted, and apply heat with a charcoal chauffer. The less diffusive heat of a lamp is apt to crack the bottom of the matrass, particularly if a large quantity of materials be employed. To prevent the heat from acting on the globular receiver, a thin disc of wood, having a round hole in its centre, is placed over the shoulder of the matrass. As soon as the upper vessel becomes warm, another is to be put in its place, and thus the two may be used in rotation as long as violet fumes arise*.

This body was discovered in 1812, by M. Courtois, of Paris. Vauquelin, (*Annales de Chimie*, tom. xc.) Gay Lussac,

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* Small quantities of iodine have been detected in several sea-weeds, and also in sponge, and the efficacy of the cinders of these substances in bronchocele, and some glandular complaints, has been plausibly referred by Dr. Coindet, of Geneva, to the iodic salts which they contain; he has also advantageously used iodine in the cure of bronchocele (*Quarterly Journal*, x. 191, xi. 407.)—The best form of iodine for medical use, seems to be the alcoholic solution in the proportion of 48 grains of iodine to two ounces of alcohol (sp. gr. 825). Of this solution from ten to twenty drops may be taken twice or thrice a day; if it materially accelerates the pulse, producing cough, palpitation, and restlessness, it should be discontinued, or the dose diminished.

Some useful directions for the preparation of iodine will be found in the *Philos. Magazine*, vol. xl. See also a note upon the subject by M. Souberan.—*Quarterly Journal, N. S.*, iv., 205.

(*ib.* xc.) Davy, Gaultier de Claubry, and Colin (*ib.* xc., xci., and xciii.)—(*Phil. Trans.*, 1814,) have fully investigated its properties.

Iodine has a bluish black colour; its lustre is metallic. It is a non-conductor of electricity. It is not changed by passing through a red-hot tube, either alone or over charcoal. It is soft and friable. Its specific gravity = 4.946. It produces a yellow stain upon the skin. Its smell resembles that of diluted chlorine; its taste is acrid. It is extremely volatile, and at a temperature between 60° and 80°, produces a violet vapour [*]. In the state of vapour, 100 cubical inches of iodine weigh 264.75 grains. At 120° or 130° it rises more rapidly. At 220° it fuses, and produces copious violet-coloured fumes, which condense in brilliant plates, and acute octoëdrons. At 350° it boils rapidly. Like chlorine and oxygen, it is electro-negative; and therefore attracted by the positive surface of the Voltaic pile. It renders vegetable colours yellow. It is very sparingly soluble in water, that liquid not holding more than $\frac{1}{7000}$ its weight in solution. The colour of the solution is yellow. It gives out no oxygen by exposure to sunshine, nor does it bleach; it however loses its own colour, and gives rise to the formation of iodic and of hydriodic acid. It is much more soluble in spirit of wine and in ether, forming deep brown solutions.

The peculiar appearance of the vapour of iodine is in many cases a sufficient evidence of its presence; a more delicate test, however, was discovered by Messrs. Colin and Gaultier de Claubry, in its remarkable property of forming a deep blue insoluble compound with starch. According to Professor Stromeyer, a liquid, containing 1.450000 its weight of iodine, receives a blue tinge when a solution of starch is added to it. To insure success, the iodine must be in a free state, and the solution cold, for boiling water decomposes and discolours the compound, and where the proportion of iodine is very minute, a few minutes elapse before the discoloration ensues.—*Stromeyer, in Gilbert's Annalen*, xix. 146.

Iodine and Oxygen.—The latest experiments upon the

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[*] Hence its name, from *ἰωδης*, violaceus.

mutual actions of these substances would lead us to suspect the existence of three compounds of iodine and oxygen, viz., one oxide and two acids.

Oxide of Iodine.—This compound was discovered by Professor Sementini, in attempting to combine iodine and oxygen together: a portion of it, he says, is formed when iodine is repeatedly heated in atmospheric air, but it is most rapidly produced by presenting iodine and oxygen to each other at a high temperature. For this purpose, a bladder of oxygen is affixed to one end of a copper tube, so placed as to be heated red-hot by lamps or a small charcoal fire; the other end of the tube terminates in the bulb of a tubulated retort containing iodine, which is also to be heated by a lamp: the oxygen is then propelled through the hot tube into the vapour and upon the hot iodine, and a yellow and very thick oleaginous liquid distils over, of an acrid, disgusting taste and odour, which is the compound in question. It slowly volatilises in the air, and is very soluble in water and alcohol, producing amber-coloured solutions. Phosphorus and potassium are inflamed by it. It changes the blue of litmus to green. If an alcali be poured into its solution, it is rendered colourless.

Iodous Acid.—If excess of oxygen, and a considerable degree of heat, be employed in the preceding experiment, the product is chiefly iodous acid. This acid is best obtained by introducing a mixture of one part of iodine and three of chlorate of potassa into a retort, and rapidly applying heat: a dense fluid distils over, which should be collected in a receiver cooled by a freezing mixture. It has a pungent taste and peculiarly disagreeable odour: its specific gravity exceeds that of water. It reddens litmus, and forms a yellow solution when diluted with water; it slowly evaporates when exposed to air, and rapidly volatilises at 112°. It is decomposed by sulphur, disengaging a little heat, and liberating violet vapours; sulphurous acid also decomposes it. Phosphorus and potassium are instantly inflamed by it. It is without action on carbon. It dissolves iodine. Neither its composition, nor that of the oxide, have been accurately determined.—*Quarterly Journal*, xvii., 381: *Ibid. New Series*, i. 477.

Iodic Acid (Davy, *Phil. Trans.*, 1815.)—This compound of oxygen and iodine cannot be obtained directly, for those bodies exert no mutual action. It is procured by acting upon protoxide or peroxide of chlorine by iodine. For this purpose the iodine may be introduced into a small flask, and the oxide of chlorine disengaged upon it, from a proper mixture of chlorate of potassa and sulphuric acid, with the precautions above pointed out; or 100 grains of chlorate of potassa may be introduced into a small retort, with 400 grains of liquid muriatic acid, of the sp. gr. 1.105: annex to the retort a small globular receiver, having a bent tube issuing from it, and passing to the bottom of a small flask, containing about 50 grains of iodine; carefully apply the heat of a lamp to the retort, by which oxide of chlorine will be disengaged, and which will be decomposed and absorbed by the iodine. A compound is then formed, which consists of chloriodic and oxiodic acids. The former is separable by a gentle heat, the latter remains as a white, deliquescent, semitransparent, sour, and inodorous body, very soluble in water, and of a specific gravity exceeding 2. It consists of 125 iodine, 40 oxygen, = 165.

The aqueous solution of iodic acid first reddens and then destroys vegetable colours; concentrated by evaporation it affords a pasty mass, which is *hydrated iodic acid*, and from which the water may be driven off by the careful application of a higher temperature. It acts powerfully upon the metals, and with the oxides forms a class of salts called *iodates*. Nitric, sulphuric, and phosphoric acids, when dropped into a hot saturated solution of iodic acid, form crystallized compounds of a yellow colour. Muriatic and oxalic acids decompose it.

Iodine and Chlorine—Chloride of Iodine—Chloriodic Acid.—When Chlorine is conducted into a vessel containing iodine, it is quickly absorbed, and a compound obtained, which is brown when the iodine is in excess, colourless when exactly saturated, and yellow if there be excess of chlorine. It is volatile, and may be distilled without decomposition. It tastes sour, and powerfully reddens litmus: it attracts moisture from the air, and dissolves readily in water, forming a brown solution when there is excess of iodine. It appears to decompose the water, and to form muriatic acid and a compound of iodine and oxygen; but these combinations are not permanent, for, on evaporation, chlorine is evolved and iodine liberated. The saturated compound is regarded as containing one volume of iodine and two of chlorine. (*Berzelius*, i. 258.) Sir H. Davy (*Phil. Trans.* 1814, p. 487) has described the crystalline compound obtained by subliming excess of iodine in chlorine, under the name of *chlorionic acid*, and regards it as a compound of one proportional of iodine and one of chlorine. It forms no permanent compounds with salifiable bases.

Section IV. Of Bromine.

This singular substance, first described in the *Annales de Chim. et Physique*, for August, 1826, was discovered by M. Balard of Montpelier. Bromine is usually obtained from the uncrystallisable residue of sea-water commonly called bittern; a current of chlorine is passed through this liquid, which immediately gives it an orange tint, in consequence of the evolution of bromine from its combinations: a portion of sulphuric ether is then shaken up with it, which, as it separates, is found to have abstracted the bromine, and acquired a reddish-brown tint. The ethereal solution is agitated with solution of potassa, by which bromate of potassa and bromide of potassium are formed. The latter is obtained in cubic crystals by evaporation, it is decomposed by solution of chlorine, and the bromine, being volatile, is separated by distillation, and condensed in a receiver cooled by ice. At common temperatures and pressures bromine is a deep reddish-brown liquid, of a peculiarly suffocating and disagreeable odour, whence its name (from βρωμος, *graveolentia*). Its specific gravity is about 3. It emits a brownish-red vapour at common temperatures, and boils rapidly at 116°. At a temperature somewhat below 0° it congeals into a brittle solid. It is a non-conductor of electricity, and attracted in the Voltaic circuit by the positive pole*. It suffers no change by transmission through red-hot

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* M. de la Rive has remarked a curious fact respecting the conducting power of fluids for electricity, in the habitudes of bromine and water; he found pure dry bromine a non-conductor, and perfectly pure water a *very* imperfect one; but a solution of bromine in water was a comparatively good conductor.—*Ann. de Chim. et Phys.* xxxv. 161.

tubes, and cannot, by any known process, be resolved into simpler forms of matter*. It dissolves sparingly in water, more readily in alcohol, and most abundantly in ether. It destroys vegetable colours. When a burning taper is immersed into its vapour it is speedily extinguished, the flame previously assuming a green and red tint. Phosphorus spontaneously inflames in its vapour; tin and antimony also burn in it; and it combines with potassium with explosive violence. Its action on alcaline solutions will be found analogous to that of chlorine and iodine: it stains the skin of a yellow colour; acts with energy upon most vegetable and animal substances; and is fatal to animal life; a single drop placed upon the beak of a bird immediately killed it. The specific gravity of its vapour has not been correctly determined, but its equivalent number appears to be about 75, which ought also to express its specific gravity in vapour compared with hydrogen.

Bromine and Oxygen — Bromic Acid. — One compound only of bromine and oxygen has as yet been discovered, namely, the bromic acid: it contains one proportional of bromine = 75, combined with five of oxygen = 40; its equivalent number, therefore, is 115. Bromic acid is obtained by the decomposition of a solution of bromate of baryta by sulphuric acid; sulphate of baryta is precipitated, and a solution of bromic acid obtained, which may be concentrated by slow evaporation; at a high temperature it is partly decomposed, so that it cannot be obtained anhydrous. It is sour, inodorous, and first reddens, and then destroys the blue of litmus. It is partially decomposed by concentrated sulphuric acid, but not by nitric acid. It is decomposed by sulphurous acid, by sulphuretted hydrogen, and by hydriodic and hydrochloric acids.

Chloride of Bromine.—By passing chlorine through bro-

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* Bromine has been suspected to be a compound of iodine and chlorine, and M. Dumas was said to have obtained such a compound possessed of the characters of bromine; an experiment, however, of M. de la Rive disproves the correctness of the conclusion. "He finds that when a compound of bromine and iodine is mixed with starch and exposed to the influence of galvanism, bromine appears at the positive and iodine at the negative wire, where the starch acquires a blue tint. On making the experiment with bromine containing a little bromide of iodine, the same appearance ensues; but if iodine is not previously added, the starch does not receive a tint of blue."

mine, and condensing the vapours at a low temperature, a reddish-yellow fluid is obtained, having a penetrating odour and disagreeable taste. It is very fluid and volatile, emitting yellow vapours; it dissolves in water, and the solution destroys vegetable colours: it would appear, therefore, not to decompose water. Chlorine decomposes most of the compounds of bromine, and hence is useful as a test of its presence. When dropped, for instance, into a weak solution of bromide of potassium, or of sodium, the evolution of bromine is manifested by the yellow colour that is produced, and by the odour of the vapour of bromine.

Iodide of Bromine.—Iodine and bromine probably combine in two proportions, but the compounds have not been analysed. In certain proportions, probably one proportional of iodine and one of bromine, a solid body is obtained, which yields reddish-brown vapours when heated, and these readily condense into arborescent crystals. A further addition of bromine dissolves these, forming a dark-coloured liquid, soluble in water, possessed of bleaching qualities, and yielding bromides and iodides with the alcalies.

Bromine probably exists in sea-water in the state of hydrobromate of magnesia, but its relative proportion must be exceedingly minute. One hundred pounds of sea-water taken up at Trieste, afforded, by M. Balard's process, 5 grains of bromide of sodium = 3.3 grains of bromine. It would appear, that in the sea-water at Trieste the bromine is unaccompanied by any iodine; and the same is the case, according to M. Hermbstadt, with the waters of the Dead Sea. In the water of the Mediterranean, on the contrary, iodine is always found with bromine. It is most readily recognised by evaporating the water, so as to separate all its more ordinary crystallisable contents, reducing the remainder to a very small bulk, and dropping in a concentrated solution of chlorine. The appearance of a deep yellow tint announces bromine. It has thus been discovered, not only in the waters of the ocean, but in certain salt springs, in the ashes of marine plants, and in those of some marine animals.

Section V. Of Fluorine.

This substance has not hitherto been obtained in an insulated state, for its powers of combination are such, that no body has been found capable of resisting its energetic action. The evidence of its existence, as a distinct electronegative element, will be more clearly understood by reference to the account of its compound with hydrogen (See Hydrofluoric Acid), and to the experiments of Sir H. Davy (*Phil. Trans.* 1813, p. 263, and 1814). Its equivalent number is probably = 16. It is found as a component part of a few mineral substances only; one of these, however, commonly called *fluor spar*, is very abundant, and appears to be a compound of fluorine and calcium, or a *fluoride of calcium*. No compound of fluorine with oxygen, chlorine, iodine, or bromine, has yet been shown to exist.

It may be remarked of the bodies which have been described in this chapter, that although they combine with each other, they do not appear possessed of powerful mutual affinities; and, consequently, their compounds are, with few exceptions, either unstable, or easily decomposed: this is what might be expected as a consequence of their analogous electrical states; for they are all attracted by the positive surface in Voltaic arrangements, and, consequently, as a class, are electro-negative. Yet, in respect to each other, they may exhibit opposite, though feeble electrical energies, and hence the possibility of such compounds in Voltaic decomposition, presenting one of their elements at the negative pole; a mixed solution, for instance, of bromine and iodine, when electrically decomposed, evolves bromine at the positive, and iodine at the negative surface, which shows that the iodine is electro-positive in respect to bromine. Oxygen is in all cases evolved at the positive pole. The compounds of the bodies described in this chapter, with those in the succeeding chapters, that is, with the simple inflammables and with the metals, when subjected to electrical decomposition, invariably give up the inflammable body at the negative pole, while the supporter of combustion appears at the positive pole.

CHAPTER IV.

OF THE SIMPLE ELECTRO-POSITIVE INFLAMMABLE SUBSTANCES.

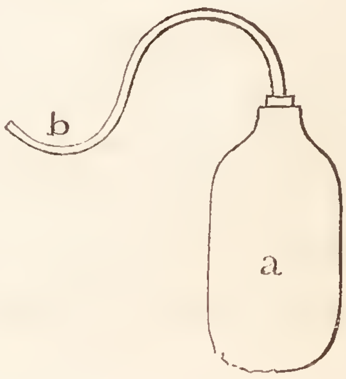
The bodies belonging to this class are electro-positive, and consequently, when separated from their combinations with the substances described in the last Chapter, by Voltaic electricity, they are attracted by the negative surface. With very few exceptions, they combine with the supporters of combustion already described; and as, of these compounds, one or more are acids; they have often been designated *acidifiable* bodies. They are seven in number :—

1. Hydrogen.
2. Nitrogen.
3. Sulphur.
4. Phosphorus.
5. Selenium.
6. Carbon.
7. Boron.

Section I. Hydrogen.

Hydrogen was first duly examined in a pure state by Mr. Cavendish, in 1766. (*Phil. Trans.*, vol. lvi. 144.)

It had before been confounded with several of its compounds under the name of *inflammable* air: the term *hydrogen* was given to it by the French chemists, in consequence of its being one of the elements of water (from υδωρ). It also forms a component of all vegetable and animal products, and is therefore abundantly diffused throughout nature.

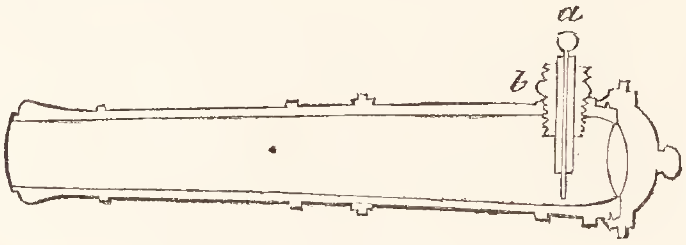


It may be obtained by the action of iron or zinc upon dilute sulphuric acid. Some pieces of iron-wire, or of zinc, may be introduced into the flask *a*, and covered with sulphuric acid diluted with six times its bulk of water; an effervescence ensues, much heat is evolved, and the gas escapes by the bent tube *b*, which is inserted by grinding into the neck of the flask, and may be collected in the hydro-pneumatic apparatus. The hydrogen, however, which is thus obtained is never perfectly pure. When procured by the means of iron, its odour is peculiarly disagreeable, in consequence, according to Berzelius (*Lehrbuch*, 186), of its containing a portion of volatile oil, formed by its union with a minute quantity of carbon, which all common iron contains. When such gas is passed through alcohol, much of the odour is absorbed by it, and on diluting it with water it becomes milky. Obtained by means of zinc, it is perhaps somewhat more pure, but it appears to hold a little zinc in solution, and often traces of sulphur and of arsenic. For the purposes of delicate experiments, hydrogen must be passed through a solution of potassa, collected over mercury, and should be procured from purified zinc, and sulphuric acid so far diluted as to act but slowly upon the metal. The hydrogen liberated by the Voltaic decomposition of water by platinum wires (*See* WATER), may, when dried, be considered as absolutely pure. This gas is also in a state of extreme purity when liberated from pure water by the action of an amalgam of potassium or of sodium.

Hydrogen is an uncondensable aëriform fluid, not absorbable by water, unless that liquid has been previously deprived by boiling of common air, in which case 100 cubical inches dissolve about 1.5 cubic inches of the gas. It has no taste, and when perfectly pure is inodorous, but it usually has a slightly disagreeable smell. It has great power of refracting light; its refractive power, compared with common air, is as 6.61436 to 1.00000. It may be respired for a short time, though it is instantly fatal to small animals. M. Maunoir, after having breathed a quantity of pure hydrogen, found that his voice had become remarkably shrill.—*Phil. Mag.* iv. 214. It is the lightest body known; and we therefore conveniently assume it as unity in speaking of the specific gravity of gases, as well as in referring to the proportions in which bodies combine. In consequence of its extreme lightness, it is difficult to determine its weight with accuracy by the common process; the researches of Berzelius and Dulong, and of Dr. Prout, lead us to consider its specific gravity, compared with oxygen, as 1 to 16: 100 cubic inches, therefore, weigh at mean temperature and pressure only 2.118 grains, and compared with air, its specific gravity is as 0.0694 to 1.

Hydrogen is inflammable, and extinguishes flame. When pure, it burns quietly, with a lambent blue flame at the surface in contact with air; but, if mixed with thrice its volume of air, it burns rapidly, and with detonation. In making this experiment, a strong phial, capable of holding about six ounces of water, may be employed; or the *inflammable air-pistol*, which admits of the mixture being fired by the electric spark.

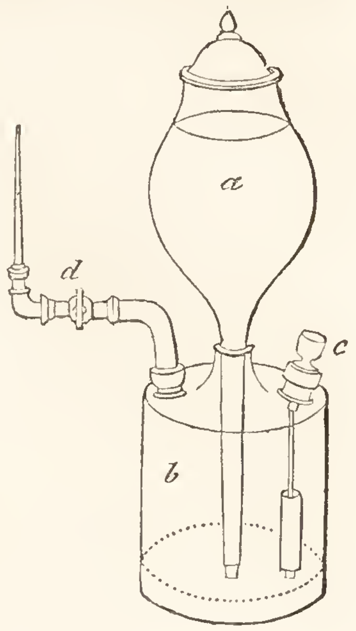
This instrument consists of a cylinder of brass, about three-fourths of an inch diameter, and six inches long, in the form of a small cannon or pistol-barrel, properly mounted, and having a wire, *a*, passing through a tube of ivory, *b*, and not quite touching the interior of the cylinder, at the part usually occupied by the touch-hole; an electric spark communicated to this wire inflames the mixture of hydrogen and atmospheric air in its interior. It may be charged by previously filling it with dry sand, and emptying it out into a phial of hydrogen, which rises into the gun sufficiently mixed with air; the muzzle may be secured by a cork, which is expelled with much violence and a loud report, upon the inflammation of the gas.



In examining into the quantity of atmospheric air required to form an explosive mixture with hydrogen, Mr. Cavendish found the loudest report was produced by two volumes of hydrogen with six of air. One of hydrogen with nine of air burned very feebly, and four of hydrogen with one of air burned without explosion.—(*Phil. Trans.* lvi.)

The electrical air-gun may be also charged, by holding it for a moment over the open jet of the following instrument, always taking care that there is a due admixture of atmospheric air, otherwise the electric spark will not inflame it.

a is a funnel-shaped vessel, fitting by a ground-joint into the three-necked bottle *b*; to the stopper *c* is annexed a brass wire, with a cylinder of zinc screwed upon its lower end; *d* is a tube furnished with a stop-cock and jet-pipe; the capacity of the vessel *a* should be nearly equivalent to that of *b*, and may contain three or four pints. To charge this apparatus with hydrogen, *b* is three-fourths filled with water, and the stopper *c* being removed, a quantity of sulphuric acid, previously diluted with its bulk of water, is poured in by a long funnel, so that it may remain at the bottom of the water which now fills the vessel. The stopper *c*, with its appended piece of zinc, is then put in, and the generated hydrogen forces the dilute acid into *a*, where its pressure serves to propel the gas through *d* whenever the stop-cock is opened; the acid, at the same time descending, produces a fresh portion of hydrogen by again acting upon the zinc. This instrument is useful where small quantities of hydrogen are required for burning, charging air-guns, and other purposes.



The inflammability, as well as the low specific gravity of hydrogen, are shown in the following experiments:—Let a jar filled with this gas stand for a few seconds, with its open mouth upwards; on letting down a candle, the gas will be found to have escaped, and to be replaced by common air. Place another jar of the gas inverted, or with its mouth downwards. The gas will now be found to remain a short time in the jar, being prevented from escaping upwards by the bottom and sides of the vessel—(*Henry.*) Provide an air-jar, with a stop-cock and jet, and fill it with hydrogen, upon the shelf of the pneumatic trough; then set fire to the gas at the jet, and whilst it is there burning slowly, lift it out of the water, and hold it firmly by the brass cap. The flame will continue for some time at the jet, the hydrogen being propelled through it by its lightness; but when the air becomes mixed in such proportions with the gas as to form an explosive mixture, the flame recedes through the jet, and the whole kindles suddenly. —(*Berzelius.*)

If two volumes of hydrogen and one of oxygen be burned in the phial or air-gun, the explosion is extremely violent; but if the mixture be diluted with eight measures of hydrogen, or with nine of oxygen, it becomes uninflammable.

A current of hydrogen may be inflamed when issuing from a small aperture, and if a tube of 18 or or 20 inches in length be held over the flame, a peculiar musical tone is produced. This effect is not peculiar to hydrogen, but is produced by a variety of other flames (Faraday, *Journal of Science and the Arts*, vol. v.), and is referable to the succession of explosions produced by the combustion of the gas in the tube.

The tendency which gaseous fluids have to become completely mixed under all circumstances, and as it were to penetrate each other, is well illustrated where hydrogen is employed. Thus, if two small phials, the one containing oxygen and the other hydrogen, be connected perpendicularly by a long glass tube, of small bore, it will be found, that although the hydrogen be uppermost, and much lighter than the oxygen, it will, in the course of a few hours, have perfectly mixed with the oxygen, and the gases will be found in equal proportions in both phials. Mr. Dalton has shown that gases, unlike other fluids, do not remain upon each other without admixture.—*Manchester Memoirs*, vol. i. New Series.

Hydrogen, in consequence of its extreme lightness, is employed for filling air-balloons, and is elegantly applied to the purpose of obtaining instantaneous light in Volta's inflammable air-lamp.

The flame of hydrogen is occasionally employed for exciting intense heat; and it has been found, when mixed with oxygen, and burned as the mixture issues from a small jet, to excite a temperature nearly equal to that of the arc of flame in the Voltaic circuit. A blow-pipe upon this construction was first made by Mr. Newman, at the suggestion of Mr. Brooks, and afterwards improved, as to its safety, by Professor Cumming, of Cambridge.—*Journal of Science and the Arts*, i. 65, and ii. 380. It always, however, remains a dangerous instrument, and nearly as intense a temperature may be safely produced by propelling oxygen through the flame of a spirit lamp. A full account of the construction and use of the hydro-oxygen blow-pipe will be found in Dr. Clarke's book upon the subject. —London, 1819.

Hydrogen and Oxygen—Water.—When two volumes of pure hydrogen gas are mixed with one volume of pure oxygen gas, and the mixture inflamed in a proper apparatus by the electric spark, the gases totally disappear, and the interior of the vessel is covered with drops of pure water, equal in weight to that of the gases consumed.

If pure water be exposed to the action of Voltaic electricity, it is resolved into two volumes of hydrogen, disengaged at the negative pole, and one volume of oxygen, disengaged at the positive pole; so that water is thus proved by synthesis, and by analysis, to consist of two volumes of hydrogen, combined with one volume of oxygen. The specific gravity of hydrogen, compared with oxygen, is as 1 to 16; therefore the component parts of water by weight are,

One proportional of hydrogen = 1
One ditto . oxygen = 8

Equivalent of water . . = 9

or thus,

Hydrogen	Oxygen	Water
1.	8.	9.

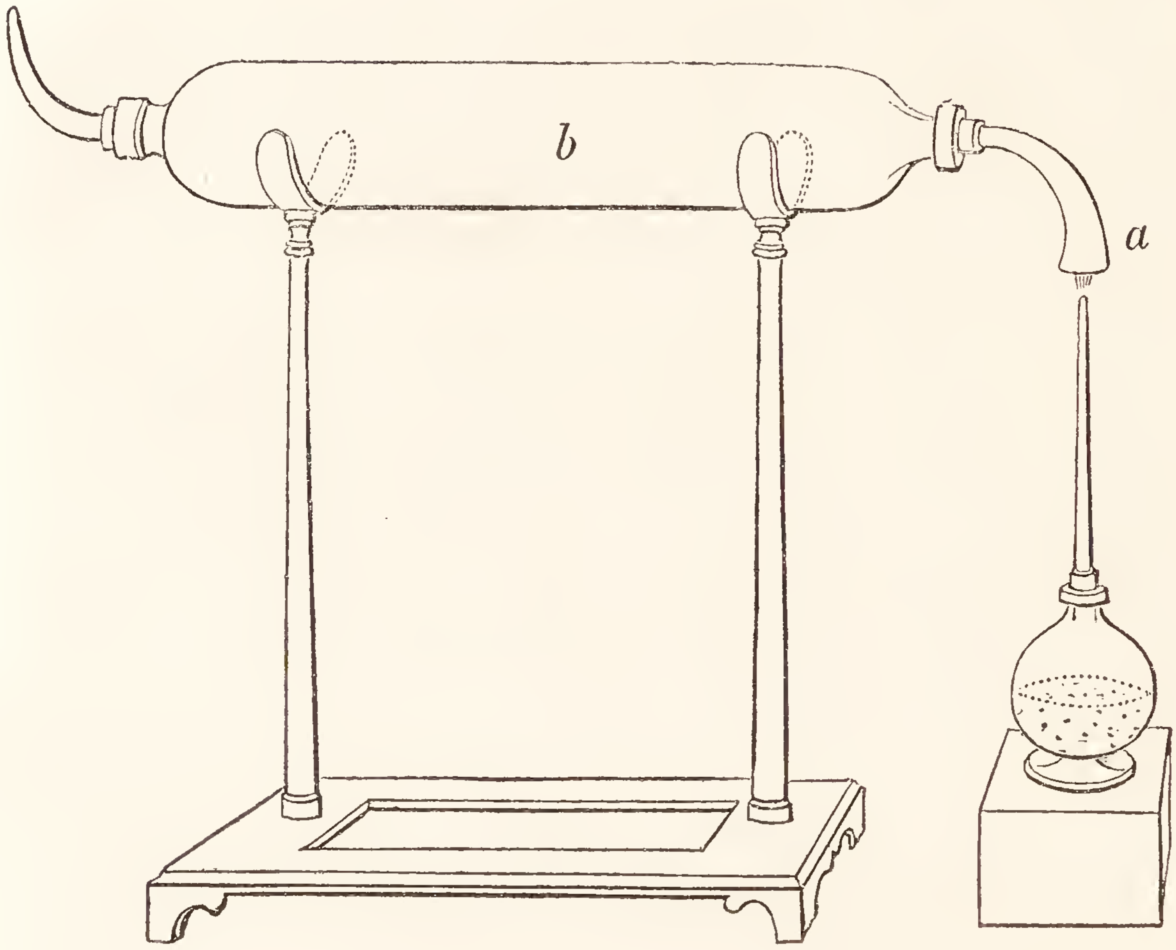
100 parts of water consists, according to the analysis of Berzelius and Dulong (*Ann. de Chim. et Phys.*, xv.) of

Oxygen . . .	88.9
Hydrogen . . .	11.1

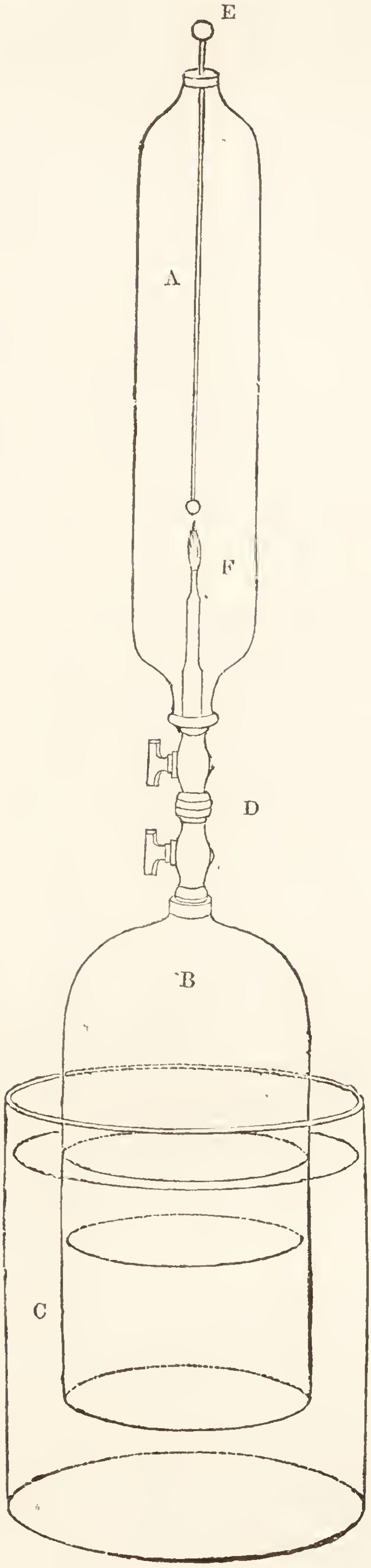
and these numbers closely agree with the proportions above given.

The experiments illustrating the composition of water, and showing the proportions in which its elements are united, are among the most important in chemistry; they may be divided into *synthetic* and *analytic*. Among these the following may be selected:—

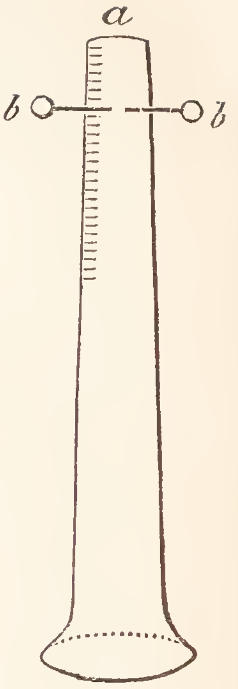
i. Burn a current of hydrogen under the copper funnel *a*, represented in the following wood-cut; by uniting with the oxygen of the atmosphere it will produce aqueous vapour, which passing into the glass cylinder *b*, will condense in drops.



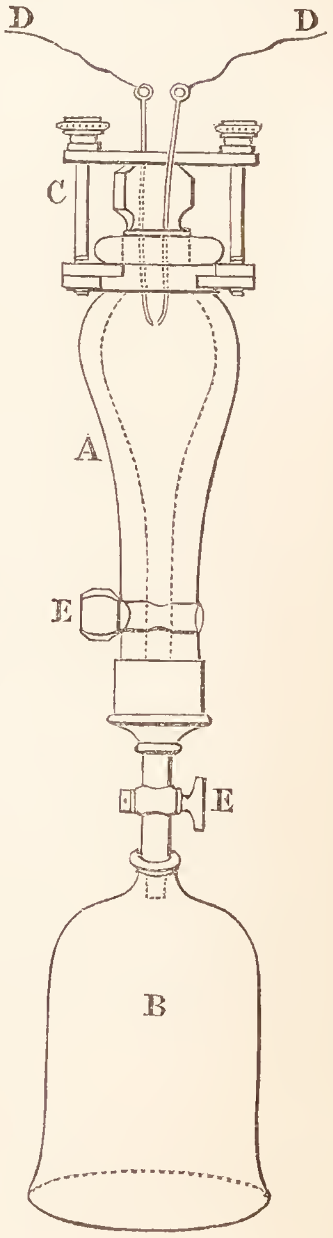
ii. The wood-cut opposite represents an apparatus for showing the production of water by burning a current of hydrogen in an atmosphere of oxygen. A is a glass cylinder, which, after having been exhausted upon an air-pump, is filled with pure oxygen. B is a receiver of hydrogen immersed in the vessel of water C, by which the gas is compressed, so as to be urged through the capillary opening F, when the stopcocks D D are open. E is a platinum wire by which the gas may be inflamed by an electric spark. It burns with the production of intense heat, and water is soon collected in drops upon the interior of the cylinder. This experiment requires to be performed with much caution, lest an explosive mixture should accidentally form within the cylinder.


E
A
F
D
B
C

iii. If two measures of pure hydrogen be mixed with one of pure oxygen, and detonated in the graduated glass tube *a*, standing over water, by an electric spark passed through the platinum wires *b b*, the gases will entirely disappear. If there be any excess of either of the gases, the portion in excess will remain unconsumed. At the moment the explosion takes place the gaseous mixture becomes greatly expanded, probably to fifteen times its original bulk (Davy *on Flame*, p. 90), and a portion is apt to escape at the bottom of the tube; hence the advantage of performing the experiment in the form of apparatus recommended by Dr. Ure. (See EUDIOMETER).



iv. The same experiment may be thus varied. A is a very strong and thick glass vessel provided with a glass stop-cock E, and with a ground stopper firmly secured by the brass collar C, through which the platinum wires D D pass. The vessel A being exhausted of air, is placed upon the bell-glass B, in the pneumatic trough, containing a mixture of pure oxygen and hydrogen in the above-mentioned proportions. Upon opening the stop-cocks E E, a quantity of the mixed gases passes into A, where, after having carefully closed the stop-cocks, it may be inflamed by an electric spark passed through the platinum wires. At the instant of the detonation a vivid flame pervades the upper vessel, and it becomes lined with moisture. If the stop-cocks be again opened, a fresh portion of the mixed gases enters, and may be inflamed as before.



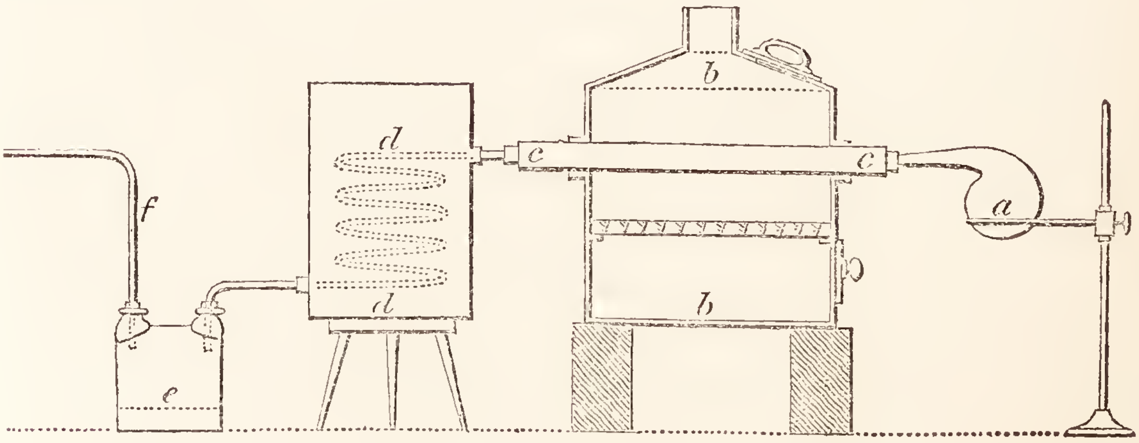
v. A mixture of oxygen and hydrogen gases, suddenly submitted to violent mechanical compression, unite with combustion, and produce water. (*Biot.*) Water may also be produced by heating the mixed gases to a temperature below that required for their combustion with flame. (Davy *on Flame,* 68.) According to Grotthus, no explosion takes place in a mixture of two volumes of hydrogen and one of oxygen, expanded to six times its volume by heat, or to sixteen times its volume by diminished pressure. (*Ann. de Chim.* lxxxii.) Electric sparks, however, passed for some time through such a mixture gradually produce water. A red heat, visible by daylight, inflames the mixture; but a very dull red heat only causes the combination of the gases without explosion.

vi. A very curious discovery connected with the present subject was made in the year 1824, by Professor Dobereiner, of Jena, who found that spongy platinum (See Platinum among the Metals) possessed the singular property of causing the immediate combination of hydrogen and oxygen, with heat sufficient to inflame the gases, and of course to render the metal red-hot. If a small piece of well-prepared spongy platinum be held in a jet of hydrogen issuing from a small tube into the atmosphere, it immediately becomes hot enough to inflame the gas. If a mixture of oxygen and hydrogen, or of atmospheric air and hydrogen, not in explosive proportions, be submitted to the action of the platinum, it disposes the gases to slow combination, water is gradually formed, and if there be a sufficiency of oxygen, the whole of the hydrogen disappears under its influence; if, on the other hand, there be excess of hydrogen, the oxygen disappears. In analyzing certain gaseous mixtures, therefore, platinum, in this peculiar state of mechanical division, becomes a most valuable agent. For more convenient application to such purposes, the platinum may be mixed with an equal weight of pure clay, and moulded with a little water into small balls, which must be carefully dried at a high heat. These may be conveniently thrown up into gases standing over mercury, and their power is not impaired by use; for they may always be rendered efficient, or their power restored, by heating them in the flame of a blow-pipe. Spongy platinum also causes the union of oxygen with several other gases, such as carbonic oxide, and at high temperatures, olefiant gas; it also promotes the decomposition of nitric oxide by hydrogen (*See* Dulong and Thenard's Paper, *Ann. de Chim.*

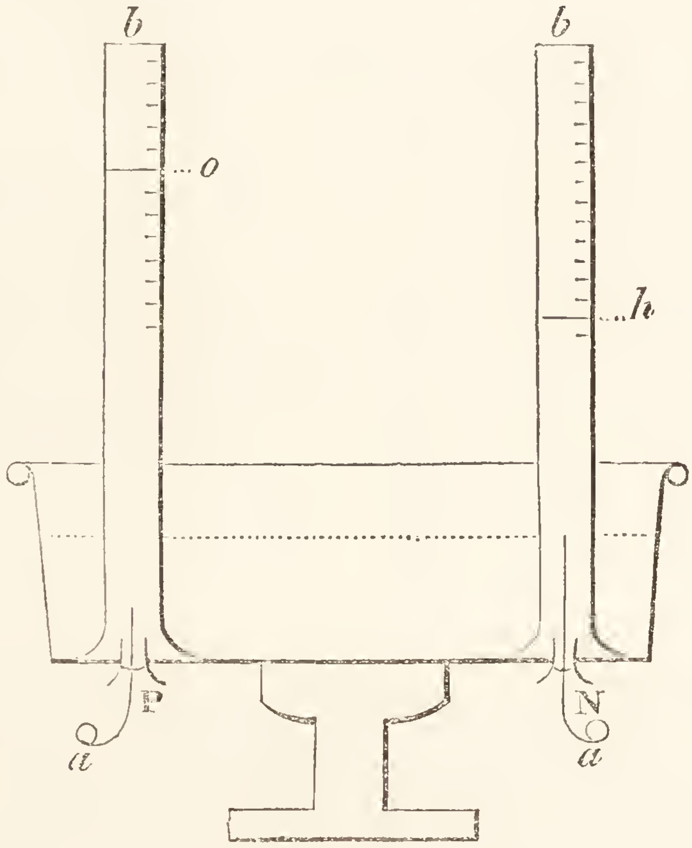
et Phys. xxiii. 440.) A very few other metals operate in the same way, but less perfectly than platinum, such as palladium and iridium. Gold and silver in fine leaves are efficient at temperatures above 212°. The cause of these phenomena has not been satisfactorily explained.

Water may be decomposed or resolved into its elements by a variety of processes, the most important of which are the following:—

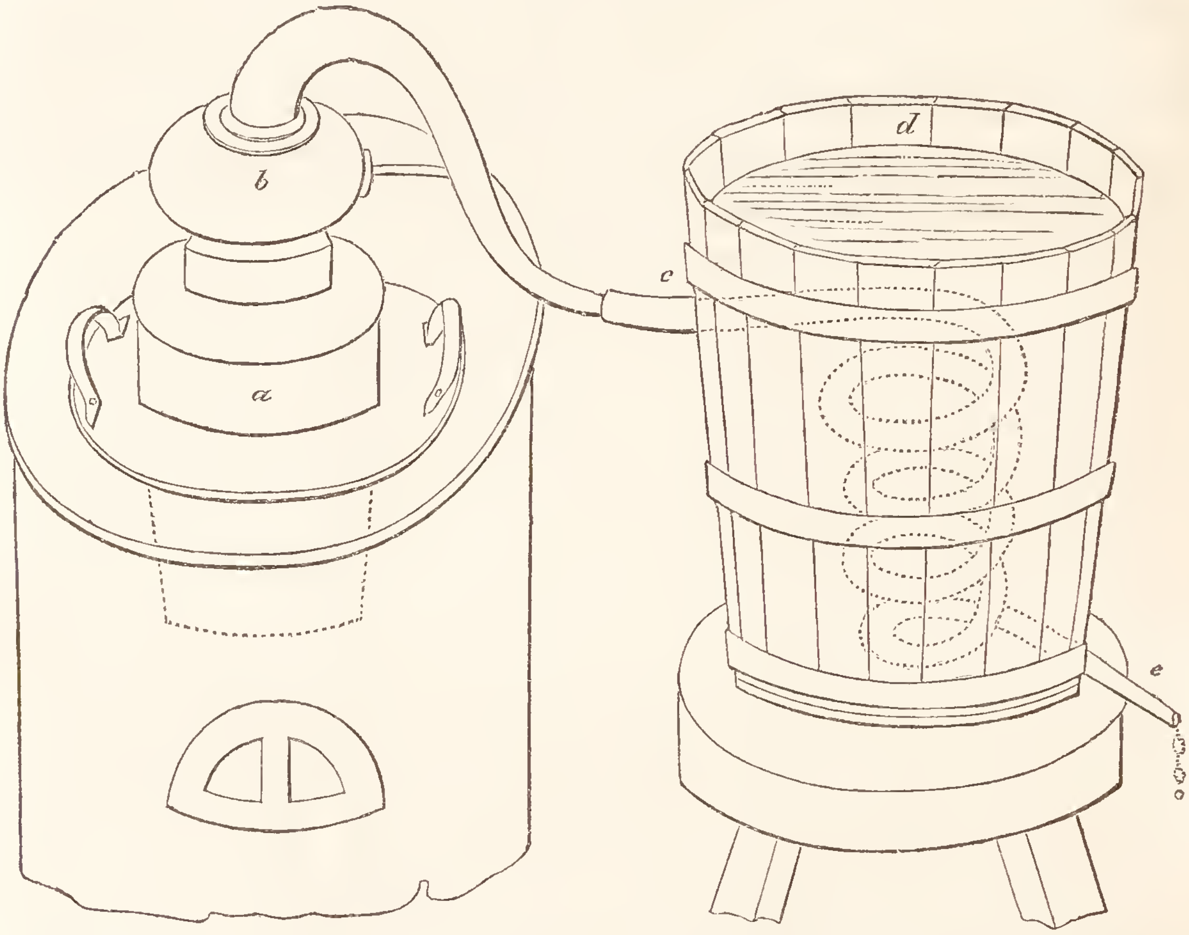
i. *a* is a glass retort, into which is introduced a given weight of water; *b b* a small furnace through which passes the earthen tube *c c*, which terminates in the spiral pewter tube *d d*, immersed in water. A given weight of pure iron wire, coiled up, is introduced into the tube *c*, and the whole made red-hot; the water in *a* is then made to boil, and the vapour, on coming into contact with the red-hot iron, is in part decomposed; the oxygen is retained by the iron, and the hydrogen escaping through the tube *f*, may be collected as usual. Any undecomposed portion of water is condensed in the worm-pipe *d*, and drops into the vessel *e*. After this experiment the iron will be found to have increased in weight; and if attention be paid to the quantity of water which has collected in *e*, and to the weight of the hydrogen gas evolved, it will be found that the weight gained by the iron, added to that of the hydrogen, will be equal to the weight of the water which has disappeared. Lavoisier concluded, from an experiment thus conducted, that water consisted of 85 per cent. by weight of oxygen, and 15 by weight of hydrogen; that is, that for every 15 grains of hydrogen evolved, 85 grains of oxygen were condensed by the iron.



ii. Decomposition by Voltaic electricity best illustrates the composition of water, since it exhibits both the oxygen and hydrogen in the gaseous form. The wood-cut below represents a section of an apparatus for this purpose. It is a glass vessel containing water, having two wires of platinum, *a a*, passing through its bottom : over these are inverted the tubes *b b*, also filled with water. The wires are rendered positive and negative by connexion with a moderately-powerful Voltaic apparatus. Oxygen is evolved at the positive wire, and hydrogen at the negative wire, which gases rise into the tubes, and it is seen that one volume of oxygen, *o*, and two volumes of hydrogen, *h*, are the constant results. If these gases be mixed and detonated, pure water is again formed.



Water, in its ordinary state, such as *spring* and *river water*, is always so far contaminated with foreign substances as to be unfit for many chemical purposes, and frequently, as will be more fully shown hereafter, even for domestic use. *Rain-water* is much more pure, but it always contains a portion of carbonic acid and of the elements of atmospheric air, besides appreciable traces of vegetable or animal matter ; to the latter it owes its property of becoming putrid when kept. The distinction of water into *hard* and *soft* has reference to its less or greater purity. The impurities of water are separated by distillation, which process is usually conducted upon the large scale in a copper *boiler, a,* placed either in a portable furnace, or set in brickwork, according to its dimensions, to which is annexed a head, *b*, of the same material, or of pewter, connected with the pewter *worm*, *c*, which is immersed in the *worm-tub*, or *refrigerator*, *d*, its lower end passing out at *e*. The water in this vessel must always be retained of a low temperature to effect the condensation of the vapour in the spiral tube.



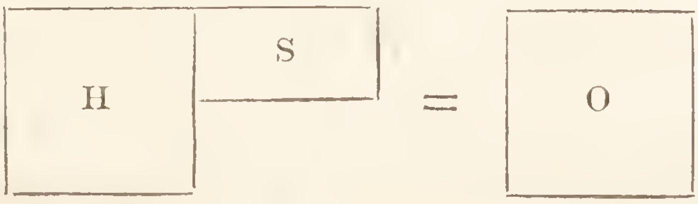
Distilled water, as commonly prepared, always affords minute traces of foreign matter, especially when subjected to Voltaic decomposition, and can only be considered as *perfectly* pure when re-distilled at a low temperature in silver vessels.

Pure water is transparent, and without either colour, taste, or smell. Several of its characters, in respect to the agency of heat, have already been noticed, more especially the singular fact respecting the temperature at which it attains its maximum density. It is a powerful refractor of light, and a very imperfect conductor of heat and of electricity. In consequence of the facility of obtaining it pure, it is assumed as a standard to which the relative weight of all other bodies may be compared, its specific gravity being called = 1.000, and hence the importance of estimating its weight with precision. At the temperature of 40° it is at its maximum of density, and at that temperature an English cubic foot weighs 437102.4946 grains (Thomson's *System*, vol. ii. p. 12), or

999.0914161 ounces avoirdupois, and a cubic inch 252.953 grains. It is therefore about 828 times heavier than atmospheric air.

At the temperature of 32° water congeals into ice, which, if slowly formed, produces needles crossing each other at angles of 60° and 120°. Their forms are various, but the primitive figure has not been ascertained, though it is probably rhomboidal. The specific gravity of ice is 0.94, or thereabouts, varying a little, in consequence of the air-bubbles which it includes: the densest ice, however, obtained by freezing water deprived of air, is always lighter than water itself. In freezing, the water expands with such force as to burst very thick and strong vessels in which it is confined. The rupture of iron and leaden pipes is a familiar instance of this power. The most interesting experiments upon the subject are those of Major Williams. (*Edinb. Phil. Trans.* vol. ii.) Bombshells, about 13 inches in diameter, and more than 2 inches thick, were filled with water; the fuse-holes were then plugged with iron bolts; and thus charged, were exposed to the open air at a temperature between – 4° and – 19°. At the moment of congelation the plugs were thrown out, and the ice protruded through the fuse-hole. When the plug was duly secured, the shell itself burst. The greatest difference observed in those experiments between the bulk of water before and after congelation was : 174 : 184. Exposed to the air, ice loses considerably in weight by evaporation.

If water be exposed to heat in open vessels it boils, or is converted into steam, at 212°, the barometer being at 30 inches; but the boiling point of water varies considerably with the pressure. The specific gravity of air being considered as = 1; that of steam is 0.6215; 100 cubical inches weighing 19.062 grains. In its constitution, two volumes of hydrogen and one of oxygen are condensed into two volumes, as in the annexed diagram. Its specific gravity, therefore, compared with hydrogen, is as 9 to 1.



At mean pressure, and at the temperature of 212°, the bulk of steam is about 1700 times greater than that of water.

Water is susceptible of compression, as was originally shown by Canton, and more lately by Mr. Perkins, who has estimated, in an ingenious series of experiments, the rate of its compression. He finds a pressure of 2000 atmospheres occasions a diminution of 1-12th its bulk. (*Phil. Trans.* 1820.) This subject has been more recently examined into by Œrsted, whose results differ from those of Perkins: the estimate of the latter he thinks too great. (*Ed. Jour. Science*, xii. 201.) If submitted to very sudden compression, water becomes luminous, as has been shown by M. Desaignes. (Thenard, *Traité de Chimie*, i. 432.)

Water enters into combination with a variety of substances, and is retained with various degrees of force: where it contributes to the regular form and transparency of crystallized bodies, it is termed *water of crystallization.* In other cases the compounds which water forms with substances are called *hydrates*, as with many of the metallic oxides; in both cases it may be considered as one of the constituents of the bodies, for it exists in them in a definite proportion.

Water, which has been exposed to the atmosphere, always contains a portion of air, as may be proved by boiling it, or by exposing it under the exhausted receiver of the air-pump. To separate the air, the water must be boiled for about two hours. It absorbs oxygen gas in preference to atmospheric air or nitrogen, and when the air is expelled by boiling, the last portions contain more oxygen than those first given off.—(Humboldt and Gay-Lussac, *Journal de Physique*, 1805.)

Mr. Dalton states, that 100 cubical inches of spring water afford about two inches of air, which, after losing from 5 to 10 per cent. of carbonic acid by the action of lime-water, consists of 38 per cent. oxygen and 62 nitrogen (*New System*, 271). Dr. Henry obtained 4.76 cubic inches of gas from 100 of the water of a deep spring, of which 3.38 were carbonic acid gas, and 1.38 air, of the same standard as that of the atmosphere. There can, however, be no doubt that the aëriform contents of different springs vary both in quantity and quality.

The following Table exhibits the quantity of different gases which water is capable of absorbing at mean temperature and pressure, the water being previously deprived of all aëriform matter by long boiling.

GASES.	100 Volumes of Water absorb	AUTHORITY.
Oxygen	3.7 volumes	Dalton
Chlorine	200	
Oxide of Chlorine	800	
Hydrogen	1.56	Henry.
Muriatic acid	50000. average	
Hydriodic acid		
Nitrogen	1.56	Henry.
Nitrous oxide	100	Ditto.
Nitric oxide	5	
Nitrous acid		
Ammonia	67000 average	
Sulphurous acid	3300	Thomson.
Sulphuretted hydrogen	100	Dalton.
Hydroguret of phosphorus	2.14	Henry.
Bi-hydroguret of phosphorus	12	Davy.
Carbonic oxide	2 average	
Carbonic acid	100	Dalton.
Carburetted hydrogen	12.5	Dalton.
Cyanogen	450	
Fluoboric acid	70000	John Davy.
Fluosilicic acid	35000	Saussure.

The great importance of water as a natural and artificial agent, both mechanical and chemical, must be sufficiently obvious. The manner in which its changes of state or form influence the temperature of the globe, will be evident by a reference to the details given in the Section on Heat. When it freezes, the expansion which it suffers, and the force with which its particles arrange themselves in the crystalline form, are often actively concerned in the disintegration and decay of rocks and strata, and in the production of soils. Water is a most general and useful solvent, especially of saline bodies, the relative solubilities of which will be stated under their individual chemical history. Considered as a chemical agent, it is frequently resolved into its elements ; these are sometimes respectively concerned in the production of new compounds : when chloride of phosphorus, for instance, acts upon water, its chlorine combines with the hydrogen of the water to form muriatic acid, and the phosphorus and oxygen unite to form phosphorous acid. In other cases bodies decompose water by the absorption of oxygen only, and the hydrogen is liberated in the gaseous form ; but there is no instance in which the hydrogen is absorbed, so as to cause the evolution of gaseous oxygen.

Peroxide of Hydrogen.—M. Thenard has shown that water may be united to a considerable excess of oxygen by means of peroxide of barium. (*Quarterly Journal*, vol. viii. p. 114.) The specific gravity of oxygenated water is about 1.45. It acts as a caustic upon the skin; detonates violently when dropped upon dry oxide of silver, or upon most of the metals finely divided. This singular compound may be termed *peroxide of hydrogen:* its properties, and the process for obtaining it, which is complex and circuitous, have been fully detailed by its discoverer, and will be adverted to under the article *Peroxide of Barium.*

As hydrogen is the lightest known substance, it is assumed in this work as *unity*, in reference to the representative numbers of other bodies. The principle of numeric representation, or of equivalent or proportional numbers, has already been adverted to, and the following will be the representative numbers of the bodies described in the foregoing chapter, the number for oxygen being deduced from the composition of water; and of chlorine, iodine, bromine, and fluorine, from the muriatic, hydriodic, hydrobromic, and hydrofluoric acids.

Undecomposed Substances.	Representative Number.
Hydrogen	1
Oxygen	8
Chlorine	36
Iodine	125
Bromine	75
Fluorine	16

Compounds.	Component Parts.			Representative Number.
Water	1 proportional of hydrogen	=	1	9
	1 ditto oxygen	=	8	
Protoxide of chlorine	1 proportional of oxygen	=	8	44
	1 ditto chlorine	=	36	
Peroxide of chlorine	4 proportionals of oxygen	=	32	68
	1 ditto chlorine	=	36	
Chloric acid	5 proportionals of oxygen	=	40	76
	1 ditto chlorine	=	36	
Perchloric acid	7 proportionals of oxygen	=	56	92
	1 ditto chlorine	=	36	
Iodic acid	5 proportionals of oxygen	=	40	165
	1 ditto iodine	=	125	
Chloriodic acid	1 proportional of chlorine	=	36	161
	1 ditto iodine	=	125	
Bromic acid	5 proportionals of oxygen	=	40	115
	1 ditto bromine	=	75	

Oxygen is resorted to by some chemists as the equivalent unit, and has been adopted by Dr. Wollaston in his researches connected with the logometric scale. Where oxygen is assumed as = 1, the equivalents may be converted into those corresponding to the unit of hydrogen, by adding to them half their sum; and again where hydrogen is = 1, the subtraction of one-third the sum gives the equivalent corresponding to the oxygen unit.

Hydrogen and Chlorine—Muriatic Acid.—When equal volumes of these gases are mixed and exposed to light, they combine, and produce a sour compound, commonly called *muriatic acid gas;* or, in conformity to more modern nomenclature, *hydrochloric acid gas.* If the above mixture be exposed to the direct solar rays, a detonation ensues, as was first remarked by MM. Gay Lussac and Thenard. (*Recherches Physico-Chymiques,* ii. 129.) It also detonates when exposed to the light of the Voltaic discharge, showing a curious analogy between electric and solar-light; for ordinary artificial light does not accelerate the combination. The moon's rays are also ineffective.—BRANDE, *Phil. Trans.* 1820. That direct solar light is not necessary to effect this combination has been shown by Professor Silliman (*American Journal of Science,* iii. 342), who relates a case of the explosion of the mixed gases in dull and cloudy daylight. This fact furnishes a caution against mixing any considerable quantities of chlorine and hydrogen. According to Dr. Henry, the agency of light on these gases may be beautifully shown by filling a tube, about half an inch diameter, and twelve inches long, with the mixed gases, and alternately shading it with an opaque cover, and exposing it to the sun's rays. The moment the tube is exposed even to the diffused light of day, a cloudiness will appear within it, and the water will ascend more or less rapidly according to the intensity of the light. The effect even of a passing cloud is distinctly seen in retarding the rapidity of the combination, which is very striking in the full solar light.—*Elements,* vol. i.

The best mode of showing the composition of muriatic acid, is to introduce into a small but strong glass vessel a mixture of the two gases, and to inflame them by the electric spark; no change of volume ensues, and muriatic gas results. The apparatus shown at page 170, may be used for this purpose.

Sir H. Davy found that the heat evolved during the combustion of a mixture of equal volumes of chlorine and hydrogen, exceeded that produced by a mixture of oxygen and hydrogen, and that the former mixture was inflamed at a lower temperature, and would bear much greater rarefaction than the latter, without losing its explosive property. Oxygen and hydrogen ceased to explode when rarefied 18 times, but chlorine and hydrogen retain their combustibility when rarefied 24 times.

Muriatic acid may be decomposed by the action of several of the metals. Potassium, for instance, absorbs the chlorine, and the hydrogen is evolved; muriatic acid gas thus affords half its volume of hydrogen. This experiment is best made by introducing a piece of potassium into a small retort, which is then to be exhausted and filled with muriatic acid gas from a jar standing over mercury. The potassium generally takes fire, but is sometimes prevented burning by the formation of a film of chloride of potassium, and then requires to be heated, which, however, should be done carefully, as the retort is apt to break in consequence of the intensity of the combustion that ensues. When it has cooled it will be found that the residuary gas is hydrogen, equal to about half the original bulk of the muriatic acid. If a piece of burning potassium be introduced in a small copper spoon into a wide-mouthed phial of muriatic acid gas, the metal continues in vivid combustion, and the evolved hydrogen, at the same time, takes fire and burns with a blue flame at the neck of the phial. Tin and lead heated in the gas also effect its decomposition, and evolve exactly half its bulk of hydrogen. As the specific gravity of hydrogen to chlorine is as 1 to 36, muriatic acid will consist of hydrogen + 36 chlorine, and its representative number will be 37.

Hydrogen.	Chlorine.		Muriatic Acid.
1	36	=	37

Muriatic acid may be readily procured by acting upon common salt or sal ammoniac by sulphuric acid; the evolved gas must be received over mercury. The salt should be put in fragments into a small tubulated retort, which may be one-fourth filled with it: the sulphuric acid should barely cover the pieces of salt; the gas is instantly extricated, and when its evolution slackens it may be quickened by the gentle heat of a lamp. It is convenient to put a long strip of folded blotting paper into the neck of the retort, which absorbs any liquid that may chance to go over, and prevents its soiling the mercury. Bottles may be filled with this gas in the way described at page 149. It was first obtained pure by Dr. Priestley, but its composition was discovered by Scheele, and has since been most ably investigated by Davy.

Muriatic acid gas is perfectly unrespirable; it extinguishes the flame of a taper. Its specific gravity, compared with hydrogen, is = 18.5: 100 cubic inches = 39.18 grains.

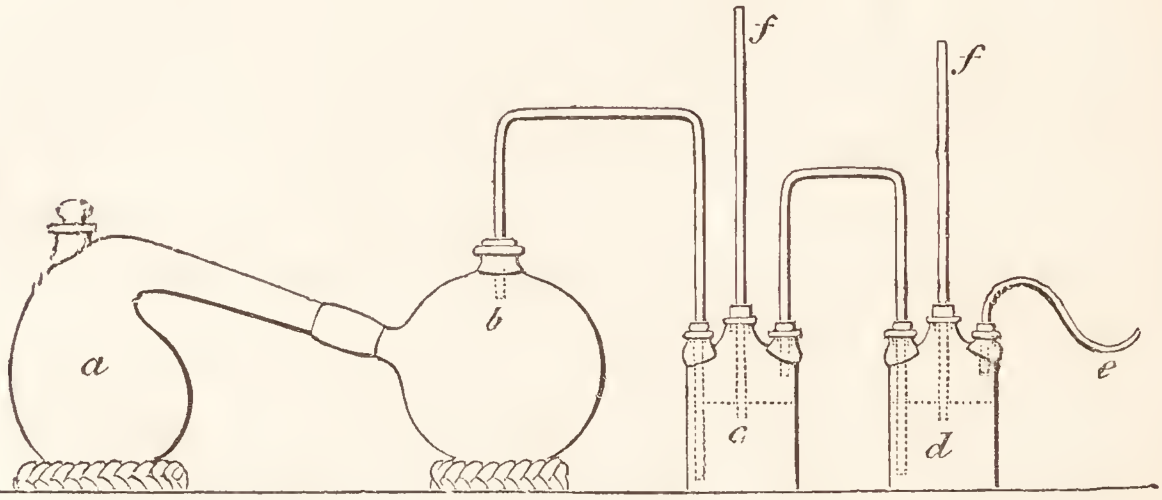
Although permanently gaseous at all common temperatures and pressures, Mr. Faraday liquefied this gas by generating it in a sealed tube, so as to expose it to a pressure of about 40 atmospheres at 50°. It was colourless, and possessed a refractive power inferior to that of water.

Muriatic acid gas has a strong attraction for water: when it escapes into the air it forms visible fumes, arising from its combination with aërial vapour. A piece of ice let up into the gas over mercury, immediately liquefies and absorbs it, and if a tall jar of the gas be carefully transferred, with its mouth downwards, from the mercurial to the water-trough, the water instantly rushes in with violence and fills it. Litmus paper is powerfully reddened by this gas, and turmeric paper receives from it a brown discolouration not unlike the effect of an alcali.

Water takes up 480 times its bulk of muriatic acid gas, and has its specific gravity increased from 1 to 1.210. This may be shown by throwing up a few drops of water, or what is better, of a blue vegetable infusion, into a tall jar of the gas standing over mercury: the gas disappears and the mercury fills the vessel. There is considerable elevation of temperature during the condensation of the gas.

Another mode of obtaining muriatic acid gas, but not a good one, consists in heating the strong liquid acid, which may be put into a small retort placed over a lamp: when it boils, the evolved gas may be collected over mercury as usual.

For saturating any quantity of water with gases which are easily soluble in that fluid, we generally employ *Woulfe's apparatus,* one form of which is shown in the annexed cut.



a, is a tubulated retort, in which the materials producing the gas or vapour, are contained; *b*, a receiver, communicating by a bent tube with the three-necked bottle *c*, which is connected also by a tube with *d*. These bottles are about half filled with water, or any other fluid intended to be saturated with the gas; when that in *c* has become saturated, it passes into *d*, and afterwards through the tube *e*, which may be placed under the water, or mercury, in the pneumatic trough. In case absorption should take place in the vessels *a* or *b*, the pressure of the external air might force the water from *d* into *c*, and from *c* into the balloon *b*. This is prevented by the safety tubes *f f*, which, dipping not more than half an inch under the surface of the water, allow a little air to enter, so as to compensate for the absorption. The different joints may be secured either by grinding, or by well-cut corks rendered tight by a mixture of drying oil and pipe clay.

When muriatic acid is thus dissolved in water, it forms the *liquid muriatic acid*, or *spirit of salt;* it may easily be procured by distilling a mixture of dilute sulphuric acid and common salt, as directed in the *London Pharmacopœia*. The most economical proportions are 32 parts of salt, and 22 of sulphuric acid, diluted with one-third its weight of water. The retort containing these ingredients may be luted on to a receiver, containing twice the quantity of water used in diluting the sulphuric acid, and the distillation carried on in a sand-bath. These are the proportions directed in the *London*

Pharmacopœia. The specific gravity of the product is stated to be 1.160, and 100 grains of it should be saturated by 124 grains of crystallized carbonate of soda. According to Phillips, a fluid ounce of the Pharmacopœia acid weighs 527 grains, and contains 32.32 per cent. of real acid. The quantity of real acid in muriatic acid of different densities, is, however, best ascertained by the quantity of pure carbonate of lime (Carrara marble, for instance), which a given weight of the acid dissolves. Every 50 grains of the carbonate are equivalent to 37 of real acid.

Upon the large scale an apparatus of earthenware is used, similar to that described under the article Nitric Acid, and to ensure the complete decomposition of the salt, rather more sulphuric acid than that just mentioned must be employed. On this account, the Edinburgh College recommend equal weights of salt, acid, and water; and Dr. Turner says, the process is practically good. The acid, to prevent too violent effervescence, at first is mixed with one-third of the water; and when the mixture has cooled, it is poured upon the salt previously introduced into a glass retort; the distillation is continued to dryness, and the gas, as it escapes, is conducted into the remainder of the water. The specific gravity of the acid obtained by this process is 1.170.

When this liquid acid is pure, it is perfectly colourless, but it generally has a yellow hue arising from particles of cork or lute that have accidentally fallen into it, or sometimes from a little iron. The acid of commerce almost always contains iron and sulphuric acid, and sometimes nitric acid. The iron may be detected by the black tint produced by tincture of galls, in the acid previously saturated by carbonate of potassa of soda; if a dilute solution of chloride of barium, dropped into the acid, occasion a white cloud or precipitate, it announces sulphuric acid. The presence of nitric acid is shown by boiling some gold leaf in the suspected muriatic acid, and then dropping into it a solution of protomuriate of tin, which, if nitric acid were present, produces a precipitate of a purplish tinge, showing the gold to have been acted upon, which it is not by pure muriatic acid. Common salt, and most other saline substances, may be detected by evaporating the acid to dryness: when pure, it leaves no residue.

The concentrated liquid acid emits fumes when exposed to air ; it boils at a temperature of 112°, and gives off the gaseous acid : it freezes at — 60°. When mixed with water, it occasions a slight elevation of temperature. It is decomposed by many substances containing loosely-combined oxygen, such as chloric, iodic, and bromic acids, and several of the metallic peroxides. Its decomposition by peroxide of manganese for the production of gaseous chlorine, has already been referred to : in this case, oxygen is imparted by the oxide to the hydrogen of the acid, so as to form water, and the chlorine previously in combination with the hydrogen is liberated ; at the same time a muriate of the protoxide of manganese is formed. The decomposition of muriatic by nitric acid will be afterwards explained. Uncombined muriatic acid is not found in nature, except as an occasional volcanic production.

The following Table shows the quantity of real acid contained in 100 parts of liquid acid of different specific gravities. —Davy's *Elements*, p. 253.

TABLE, Showing the Quantity of real Acid in Liquid Muriatic Acid of different Specific Gravities. (Temperature 45° Fah. Barometer, 30.)

Specific Gravity.	100 Grains contain of Muriatic Acid Gas	Specific Gravity.	100 Grains contain of Muriatic Acid Gas
1.21	42.43	1.10	20.20
1.20	40.80	1.09	18.18
1.19	38.38	1.08	16.16
1.18	36.36	1.07	14.14
1.17	34.34	1.06	12.12
1.16	32.32	1.05	10.10
1.15	30.30	1.04	8.08
1.14	28.28	1.03	6.06
1.13	26.26	1.02	4.04
1.12	24.24	1.01	2.02
1.11	22.30		

For the following Table, exhibiting the composition of liquid muriatic acid at different densities, we are indebted to Dr. Ure ; the data upon which it is formed, and several important facts connected with this inquiry, will be found in his paper published in the *Quarterly Journal of Science*, vol. xii. p. 286. The Table is corrected from the last edition of his Dictionary.

NEW TABLE OF MURIATIC ACID, BY Dr. URE *.

Acid of 1.20 in 100.	Specific Gravity.	Chlorine.	Muriatic Gas.	Acid of 1.20 in 100.	Specific Gravity.	Chlorine.	Muriatic Gas.
100	1.2000	39.675	40.777	50	1.1000	19.837	20.388
99	1.1982	39.278	40.369	49	1.0980	19.440	19.980
98	1.1964	38.882	39.961	48	1.0960	19.044	19.572
97	1.1946	38.485	39.554	47	1.0939	18.647	19.165
96	1.1928	38.089	39.146	46	1.0919	18.250	18.757
95	1.1910	37.692	38.738	45	1.0899	17.854	18.349
94	1.1893	37.296	38.330	44	1.0879	17.457	17.941
93	1.1875	36.900	37.923	43	1.0859	17.060	17.534
92	1.1857	36.503	37.516	42	1.0838	16.664	17.126
91	1.1846	36.107	37.108	41	1.0818	16.267	16.718
90	1.1822	35.707	36.700	40	1.0798	15.870	16.310
89	1.1802	35.310	36.292	39	1.0778	15.474	15.902
88	1.1782	34.913	35.884	38	1.0758	15.077	15.494
87	1.1762	34.517	35.476	37	1.0738	14.680	15.087
86	1.1741	34.121	35.068	36	1.0718	14.284	14.679
85	1.1721	33.724	34.660	35	1.0697	13.887	14.271
84	1.1701	33.328	34.252	34	1.0677	13.490	13.863
83	1.1681	32.931	33.845	33	1.0657	13.094	13.456
82	1.1661	32.535	33.437	32	1.0637	12.697	13.049
81	1.1641	32.136	33.029	31	1.0617	12.300	12.641
80	1.1620	31.746	32.621	30	1.0597	11.903	12.233
79	1.1599	31.343	32.213	29	1.0577	11.506	11.825
78	1.1578	30.946	31.805	28	1.0557	11.109	11.418
77	1.1557	30.550	31.398	27	1.0537	10.712	11.010
76	1.1536	30.153	30.990	26	1.0517	10.316	10.602
75	1.1515	29.757	30.582	25	1.0497	9.919	10.194
74	1.1494	29.361	30.174	24	1.0477	9.522	9.786
73	1.1473	28.964	29.767	23	1.0457	9.126	9.379
72	1.1452	28.567	29.359	22	1.0437	8.729	8.971
71	1.1431	28.171	28.951	21	1.0417	8.332	8.563
70	1.1410	27.772	28.544	20	1.0397	7.935	8.155
69	1.1389	27.376	28.136	19	1.0377	7.538	7.747
68	1.1369	26.979	27.728	18	1.0357	7.141	7 340
67	1.1349	26.583	27.321	17	1.0337	6.745	6.932
66	1.1328	26.186	26.913	16	1.0318	6.348	6.524
65	1.1308	25.789	26.505	15	1.0298	5.951	6.116
64	1.1287	25.392	26.098	14	1.0279	5.554	5.709
63	1.1267	24.996	25.690	13	1.0259	5.158	5.301
62	1.1247	24.599	25.282	12	1.0239	4.762	4.893
61	1.1226	24.202	24.874	11	1.0220	4.365	4.486
60	1.1206	23.805	24.466	10	1.0200	3.968	4.078
59	1.1185	23.408	24.058	9	1.0180	3.571	3.670
58	1.1164	23.012	23.650	8	1.0160	3.174	3.262
57	1.1143	22.615	23.242	7	1.0140	2.778	2.854
56	1.1123	22.218	22.834	6	1.0120	2.381	2.447
55	1.1102	21.822	22.426	5	1.0100	1.984	2.039
54	1.1082	21.425	22.019	4	1.0080	1.588	1.631
53	1.1061	21.028	21.611	3	1.0060	1.191	1.224
52	1.1041	20.632	21.203	2	1.0040	0.795	0.816
51	1.1020	20.235	20.796	1	1.0020	0.397	0.408

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* I have purposely omitted in this new Table the column of dry, or, as it was also called, real muriatic acid; first, because there is no evidence at present of the

The following Atomic Table of Liquid Muriatic Acid is taken from Dr. Thomson's *Principles of Chemistry*.

Atoms of Acid.	Atoms of Water.	Real Acid in 100 of the Liquid.	Specific Gravity.
1	6	40.659	1.203
1	7	37.000	1.179
1	8	33.945	1.162
1	9	31.346	1.149
1	10	29.134	1.139
1	11	27.206	1.1285
1	12	25.517	1.1197
1	13	24.026	1.1127
1	14	22.700	1.1060
1	15	21.512	1.1008
1	16	20.442	1.0960
1	17	19.474	1.0902
1	18	18.590	1.0860
1	19	17.790	1.0820
1	20	17.051	1.0780

Hydrogen and Iodine exert a slow action under ordinary circumstances; but when iodine is presented to nascent hydrogen, they readily unite, and produce a gaseous acid, the *hydriodic acid.* It is prepared by the action of moist iodine upon phosphorus, and must be received over mercury; which, however, soon acts upon and decomposes it, so that it should be transferred as speedily as possible into an exhausted vessel; or it may be received into a phial, as directed at page 170.

existence of any such body; and secondly, because, though it was a convenient column for finding by inspection the increase of weight which any salifiable base would acquire by saturation with the liquid acid, yet that convenience may be obtained by the following simple calculation. Since the prime equivalent of chlorine is to that of the supposed dry muriatic acid, in the ratio of 45 to 35, or 9 to 7; if we multiply the number opposite to the given specific gravity, in the chlorine column, by 9, and divide by 7, we shall have the relative quantity of the *fixable* muriatic acid.—*Journ. of Science*, xii. 267.

From the curious coincidence above noticed, we derive a very simple rule for finding the approximate value of chlorine in the liquid acid at any density. Multiply the decimal part of the number representing the specific gravity by 200, the product will be the chlorine present in 100 parts. Thus, the specific gravity is 1.0437, what is the quantity per cent. of chlorine? $0.00437 \times 200 = 8.74$. Now the tabular number is 8.729. The specific gravity being 1.059, what is the value of the chlorine in 100 parts? $0.059 \times 200 = 11.8$. The Table has 11.9. Towards the head of the Table this rule gives a slight error in excess; and towards the foot an equally slight error in defect; but the approximation is always good enough for ordinary practice, seldom amounting to one-half per cent. If to the number thus found for chlorine we add $\frac{1}{36}$ part, the sum is the corresponding weight of muriatic acid gas.

In procuring it, it is convenient to use a small retort or bent tube, into the bulb of which is introduced the moist iodine, and a small stick of phosphorus, about a tenth part of the weight of the iodine, placed in the neck above it, which can be shaken down upon the iodine when the beak of the tube or retort is placed under the inverted jar; a quantity of the gas is instantly and violently generated, and a further portion is obtained on applying the flame of a spirit lamp. In this experiment the mutual decomposition of the water and of the iodide of phosphorus ensues, and phosphorous and hydriodic acid are the results.

According to M. F. D'Arcet, hydriodic acid gas may be obtained very pure by the following process:—Hydrophosphorous acid is to be evaporated until upon the point of evolving phosphuretted hydrogen gas. It is then to be put, with its weight of iodine, into a small tube retort; the gas is liberated, upon applying a gentle heat: 100 grains of the acid, and 100 of iodine, afforded 120 cubical inches. The residue of the operation is a mixture of phosphoric acid, and of the compound of hydriodic acid and phosphuretted hydrogen.—*Ann. de Chim. et Phys.* xxxvii. 220.

Hydriodic acid is colourless, very sour, exhales fumes in the air, and smells like muriatic acid. It reddens vegetable blues. Its specific gravity to hydrogen is as 63 to 1; to air as 4.34 to 1. 100 cubic inches = 133.4 grains. It is not permanent at a red heat, for when passed through a red-hot porcelain tube it is partially resolved into iodine and hydrogen.

Hydriodic gas is rapidly and abundantly absorbed by water, but in what exact proportion has not been determined. The solution, exposed to a temperature below 260°, becomes concentrated by loss of water; at about 260° it boils, and may be distilled. The specific gravity of the strongest liquid acid is 1.7. It becomes dark coloured when kept in contact with air, in consequence of a partial decomposition, and it readily dissolves iodine, becoming of a deep brown colour. It is decomposed by nitric and sulphuric acids.

The liquid hydriodic acid is best prepared by passing sulphuretted hydrogen through a mixture of iodine and water; sulphur is deposited, and on heating and filtering the liquor, a pure solution of hydriodic acid is obtained, which may be concentrated by evaporation at a temperature below 260°.

That hydriodic acid gas consists of equal volumes of hydrogen and vapour of iodine is shown by the action of mercury, and some other metals, which by absorbing the iodine, evolve half a volume of hydrogen from one of the gas. When mixed with oxygen and passed through a red-hot tube, it is resolved into iodine and water.

It is instantly decomposed by chlorine, which produces muriatic acid, sometimes with explosion, and the blue vapour of iodine is rendered evident, but presently disappears in consequence of the formation of chloriodic acid. This decomposition is beautifully shown by suffering hydriodic acid gas to pass into a jar of atmospheric air, mixed with about a twelfth its bulk of chlorine; the violet fumes are then more permanent.

A little strong nitric acid dropped into hydriodic acid gas energetically decomposes it, with the evolution of so much heat that the gas is occasionally inflamed.

The experiments of Gay Lussac have proved the composition of hydriodic acid gas to be analogous to that of the muriatic: namely, that it consists of one volume of the vapour of iodine, and one of hydrogen; these produce two volumes of the acid. The specific gravity of the vapour of iodine to hydrogen is as 125 to 1; consequently hydriodic gas is composed of one proportional of iodine, = 125, and one of hydrogen, = 1; and its equivalent number is 126.

1	125	=	126
Hydrogen.	Iodine.		Hydriodic acid.

The hydriodic acid is not found uncombined in nature; its presence may be detected by mixing a cold solution of starch with the liquid suspected to contain it, and then adding a few drops of sulphuric acid: this liberates iodine and produces a blue tint.

Hydrogen and Bromine—Hydrobromic Acid.—Bromine and hydrogen do not act upon each other, even under the influence of the sun's rays, at common temperatures; but when bromine, phosphorus, and water, are brought into contact, a decomposition ensues analogous to that described under the article hydriodic acid ; and a quantity of gas is generated, which may be collected over mercury, or in dry phials. Hydrobromic gas may also be obtained by acting upon bromide of potassium by sulphuric acid.

This gas is colourless, sour, of a pungent and highly irritating odour, and yields dense vapours when mixed with humid air. It undergoes no change when passed through a red-hot tube, either alone or mixed with oxygen or iodine ; but chlorine decomposes it, producing vapour and drops of bromine, which, being absorbed by mercury, leaves muriatic acid. We learn, therefore, from these facts, that the attraction of bromine for hydrogen exceeds that of iodine, but is inferior to that of chlorine. The attraction of oxygen, and of bromine for hydrogen, is probably nearly equal ; for bromine does not decompose water, nor does oxygen decompose hydrobromic acid. Hydrobromic gas is not altered by mercury, but tin and potassium entirely decompose it ; the former requires the aid of heat, but potassium acts at common temperatures, diminishing the gas to half its bulk, and becoming converted into a bromide of potassium. Hence it appears that the constitution of hydrobromic acid is analogous to hydrochloric and hydriodic acids, and that it consists of equal volumes of hydrogen and bromine vapour, or by weight of 1 proportional of hydrogen = 1, and 1 of bromine = 75. The equivalent of the acid is therefore 76.

1 Hydrogen.	75 Bromine.	=	76 Hydrobromic acid.

Hydrobromic acid gas is rapidly absorbed by water ; heat is evolved, and a fuming liquid acid obtained, which is colourless when pure, but which readily dissolves bromine, and acquires a yellow colour. This acid may also be obtained by the action of sulphuretted hydrogen on bromine and water.

The liquid hydrobromic acid is instantly decomposed and discoloured by chlorine. Nitric acid also decomposes it, producing the evolution of bromine and the formation of water and nitrous acid. This mixture dissolves gold.

Hydrobromic acid is not readily decomposed by sulphuric acid; but on decomposing bromide of potassium by sulphuric acid a little sulphurous acid is generally formed.

Hydrogen and Fluorine—Hydrofluoric Acid. — When finely powdered fluoride of calcium, or fluor spar as it is usually called, (carefully selected for its purity,) is distilled with twice its weight of sulphuric acid, a highly volatile and corrosive liquid is obtained, which acts powerfully on glass and most of the metals: the retort employed in the experiment may be of lead, with a tube and receiver of pure silver; the receiver must be immersed in a mixture of ice and salt. The product is best preserved in a silver bottle, with a well-fitted stopper of the same material. When pure, it is clear and colourless, is very volatile, and smokes when exposed to air: at temperatures above 60° it flies off in vapour. Its specific gravity is 1.0609; but by the gradual addition of a certain proportion of water it acquires a considerable increase of density, the mixture having a specific gravity of 1.25. Its attraction for water exceeds that of the sulphuric acid, and when dropped into water it excites a hissing noise, and great heat is evolved. Its vapour is dangerously pungent and irritating, and the liquid acid eminently active upon organic substances: a minute drop of it upon the skin produces a painful sore, and in larger quantities dangerous and malignant ulceration: hence the vessels containing it require to be handled with great caution. Its most characteristic property is the energy with which it acts upon glass: its vapours soon destroy the polish and transparency of all neighbouring glass vessels, and when dropped upon glass great heat and effervescence are produced, and dense fumes evolved consisting of fluosilicic acid. Diluted with about six parts of water, the acid may be used for etching upon glass, which it very effectually accomplishes in a few minutes.

The nature of this powerful and peculiar acid is as yet imperfectly understood, its basis, fluorine, not having been obtained in an insulated form. All analogy, however, leads us to regard it as a compound of fluorine and hydrogen: its action upon many of the metals sanctions such a conclusion: they evolve hydrogen, and peculiar compounds result, consisting probably of the metal in combination with fluorine. The action of potassium upon this acid is very energetic; it is attended by explosion, by the liberation of hydrogen, and by the formation of a peculiar soluble saline compound, which is considered as a fluoride of potassium.

Regarding the hydrofluoric acid as a compound analogous to the hydriodic and hydrochloric acids, it will consist of—

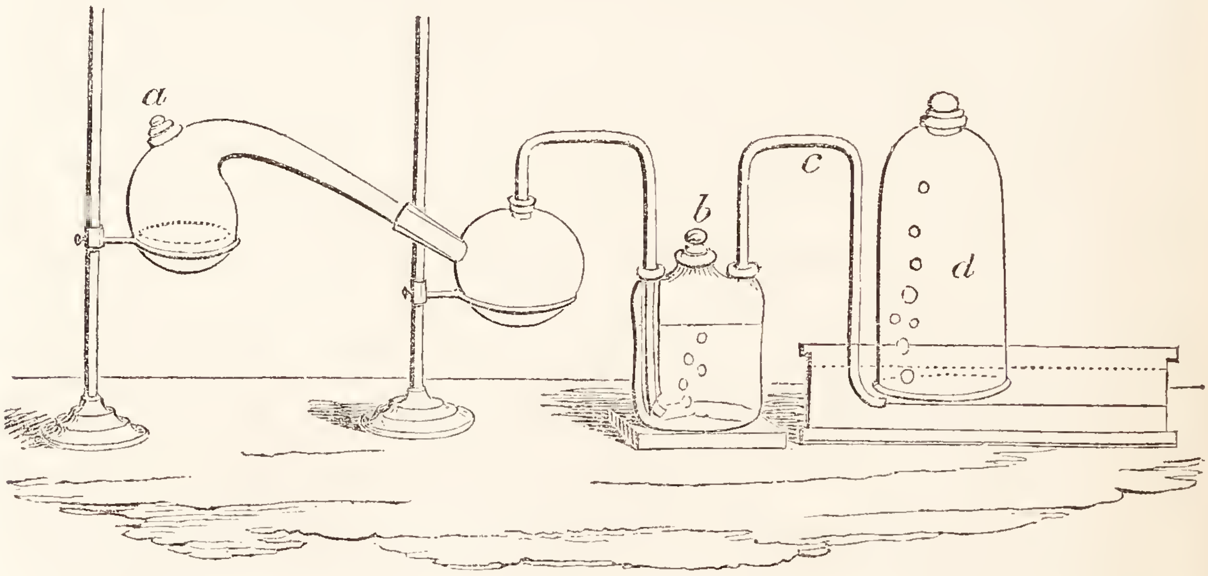
One proportional of fluorine . . .	= 16
„ „ hydrogen . .	= 1
Equivalent of hydrofluoric acid .	= 17

These numbers are deduced from Sir H. Davy's experiments upon the fluoric compounds: if the equivalent be founded upon the researches of Berzelius, the number 18.9 or 19 may be assumed as the equivalent of fluorine and 20 that of the hydrofluoric acid. (See *Fluoride of Calcium,* and *Silicated Fluoric Acid.*)

Section II. Nitrogen.

This was first recognised as a distinct aëriform fluid by Dr. Rutherford in 1772. (Thesis, *De aëre Mephitico.*) Dr. Priestley called it phlogisticated air. Nitrogen is a permanently elastic gas at all known temperatures and pressures. It may be obtained by burning phosphorus in a confined portion of atmospheric air. For this purpose a tall glass jar should be selected, open at bottom and stopped at the top; a small wedgwood basin containing a sufficiency of inflamed phosphorus is then set afloat in the water-trough, and the jar, without its stopper, immediately inverted over it. A quantity of air is at first expelled by the heat; the stopper is then replaced, and the combustion goes on for some time; when it has ceased, and the apparatus has cooled, the basin is easily removed by agitating the jar, so as to sink it through the water; the residuary gas is then thoroughly washed with lime water, and is nitrogen nearly pure.

Another mode of obtaining nitrogen which furnishes it in a state of considerable purity, consists in passing chlorine into a strong aqueous solution of ammonia. This may be done by nearly filling a Wolfe's bottle with two necks with the solution, and passing gaseous chlorine into it from a retort containing muriatic acid and oxide of manganese; a bent tube issuing from the other neck passes under the shelf of the pneumatic apparatus, and through it the nitrogen escapes, and may be collected; but care should be taken to leave excess of ammonia in the bottle. In this experiment ammonia, consisting of hydrogen and nitrogen (See AMMONIA) is decomposed by the chlorine, which unites with its hydrogen to form muriatic acid, and gaseous nitrogen is evolved: a solution of muriate of ammonia is at the same time obtained, and if excess of chlorine be used, chloride of nitrogen, which is a very dangerously explosive compound (See *Nitrogen and Chlorine*) may be formed. If the ammoniacal solution be very concentrated, the bubbles of chlorine often produce flashes of light and slight explosions: these are quite harmless, and may be prevented by dilution of the ammonia. The following is the disposition of the apparatus: *a* is the retort and tubulated receiver containing the materials for the evolution of chlorine; *b* the two-necked bottle about three-fourths filled with strong liquid ammonia; *c* a bent tube, carrying the evolved nitrogen into the water-trough, where it is collected in the inverted jar *d*.



According to Berzelius, the purest nitrogen is obtained by filling a bottle about one-third full of a liquid amalgam of lead and mercury, carefully stopping it, and agitating it with the included air for two hours or more: the highly-divided lead absorbs the oxygen, and leaves pure nitrogen. On opening the bottle under water, the liquid rushes in, and demonstrates the degree of absorption.

If equal weights of iron filings and sulphur be made into a paste with water, and exposed to a confined portion of atmospheric air, it will, in the course of forty-eight hours, absorb the oxygen, and leave the nitrogen nearly pure.

There are many other processes by which nitrogen may be obtained, some of which will be further noticed under the article "Atmospheric Air." It is also frequently evolved during the decomposition of animal matter. If lean, muscular flesh, for instance, be heated in nitric acid diluted with ten or twelve parts of water, this gas is given off, though not pure: these cases of its evolution will be more particularly explained afterwards.

Nitrogen is a colourless gas, with neither smell nor taste, having no action upon vegetable colours nor upon lime-water; neither is it absorbed by water, except that fluid has been deprived of its ordinary portion of air by long boiling, when it takes up about one and a half *per cent.* Its refractive power in regard to light is to that of atmospheric air as 1.03408 to 1.0000. It is rather lighter than atmospheric air, compared with which its specific gravity is 0.972: 100 cubic inches weigh at mean temperature and pressure 29.652 grains. Its specific gravity in reference to hydrogen is as 14 to 1.

An animal immersed in nitrogen is instantly suffocated, whence it was called by Lavoisier *azote* (from α *privative*, and ζωη life): but if that term be taken in its strict sense, all gaseous bodies (excepting atmospheric air) might be included under it; for even oxygen itself will not indefinitely support life: moreover, nitrogen, as it exists in the atmosphere, mixed with oxygen, appears to be absolutely essential to animal life; for no other gas can be substituted for it. If we consider the term *nitrogen* as merely implying that it is a component of nitric acid, it is explicit and unobjectionable; we, therefore, adopt it in preference to that of azote.

Nitrogen is, in the strictest sense of the word, a non-supporter of combustion; for all burning bodies are immediately and perfectly extinguished by it: this is the case with the flame of a taper, with phosphorus in intense combustion, and even with potassium, which, however highly heated, shows no inclination to burn in pure nitrogen.

When the compounds of nitrogen are submitted to Voltaic action, it is evolved at the negative surface; hence it is included among electro-positive bodies. How far it deserves to be called an inflammable substance, is not so obvious: its attraction for oxygen is not powerful, and the two bodies when mixed in their gaseous state show no tendency to combine; they do, however, unite in several proportions; but their compounds are formed at low temperatures; or the nitrogen and oxygen are presented to each other in their nascent states, that is, before one or both of them have acquired the independent gaseous form. The same remark applies to all compounds of this gas.

At very high temperatures, however, nitrogen may be made to undergo a kind of combustion: if, for instance, it be mixed with three volumes of oxygen, and electric sparks passed through the mixture standing over blue infusion of litmus, each spark will be attended by the production of a trace of nitric acid, and after some hundred sparks, the blue of the litmus will be changed to red. Here combustion appears to take place in that portion of the gas immediately subject to the action of the sparks; but the temperature of the surrounding gas is not thus sufficiently elevated to enable the combustion to spread beyond the immediate sparks. Berzelius has well compared this action to that which ensues when sparks are passed through a mixture of hydrogen and a large relative quantity of atmospheric air or of oxygen: in that case no general combustion of the mixture is effected; but water is slowly formed by the action of each successive spark upon the portion of the gaseous mixture immediately subjected to its heating influence.

If a mixture of nitrogen with twelve or fourteen volumes of hydrogen be set fire to as it issues from a small tube, and burned either in common air or in an atmosphere of oxygen, as in the apparatus represented at page 169, water and nitric acid will be formed; so that in this case the nitrogen may be said to undergo combustion by the aid of the elevated temperature of the flame of hydrogen; but it must be recollected that in these cases nitric acid could not be produced without the presence of water, and that it may tend to dispose an union which would not otherwise take place.

Much discussion has arisen among eminent chemists respecting the nature of nitrogen; and the question has been agitated, whether it is or is not a simple body; but although many ingenious surmises have been published on the subject, and many analogies suggested in favour of its compound nature, no experimental proofs have been hitherto adduced: the views are merely hypothetical, and dangerous to the progress of genuine chemistry; the more so in proportion to the talents with which their plausibility has been urged.

Nitrogen and Oxygen.—These bodies unite in five proportions, and form the compounds called,

1. Nitrous oxide.
2. Nitric oxide.
3. Hyponitrous acid.
4. Nitrous acid.
5. Nitric acid.

Protoxide of Nitrogen, or *Nitrous Oxide*, was discovered by Dr. Priestley, in the year 1776; he called it *dephlogisticated nitrous air:* it has also been called *gaseous oxide of azote.* It may be formed by exposing nitric oxide to the action of iron filings, or of a mixture of sulphur and iron filings, by which a portion of its oxygen is absorbed, and the remaining elements left in such proportions as to constitute nitrous oxide. But the gas thus procured is not pure. It is most easily and abundantly obtained in a state of purity, by heating, in a glass retort over an Argand lamp, the salt called *nitrate of ammonia*, to a temperature of about 420°. The gas which passes off, provided the salt be pure and the temperature not too high, may be collected over warm water, and is pure *nitrous oxide.* If the nitrate of ammonia contain a mixture of the muriate, the gas will be contaminated by chlorine; and if too much heat be used in the decomposition of the pure salt (which may be known by white vapours appearing in the retort) it will contain nitric oxide. The salt should be kept in a state of gentle ebullition, so as to maintain a quick but not violent evolution of gas.

The presence of chlorine in nitrous oxide is ascertained by its smell, and may be avoided by using pure nitrate of ammonia, the solution of which is not rendered turbid on the addition of nitrate of silver. Nitric oxide is detected by the appearance of red fumes on mixing the gas with oxygen; it may be abstracted by agitating it with a solution of proto-sulphate of iron, which has no action upon nitrous oxide, but absorbs the nitric oxide, and acquires a deep olive colour. If nitrous oxide be mixed with common air, it affords red fumes upon adding to it a few bubbles of nitric oxide, and it is not, as it ought to be, entirely absorbed when agitated with twice its bulk of water: 100 cubic inches weigh 46.596 grains; its specific gravity, therefore, to hydrogen is as 22 to 1; and to atmospheric air as 1.527 to 1000.

The taste of this gas is sweet, and its smell peculiar, but agreeable. It is easily absorbed by water, which takes up about its own bulk, and evolves it unchanged when heated. It should, therefore, be collected and preserved in stopped bottles.

Its singular effects, resembling intoxication, when respired, were first ascertained by Sir H. Davy. (*Researches Chemical and Philosophical, chiefly concerning Nitrous Oxide.* London, 1800.) The experiment of breathing this gas, however, cannot be made with impunity, especially by those who are liable to a determination of blood to the head. The following accounts of its effects when respired will serve to give a general idea of its singular powers. They are quoted from Sir H. Davy's "Researches," a work in which many important details concerning the effects of different gaseous bodies upon the system will be found. The first account is by Mr. Tobin, and the second by Dr. Roget: upon myself, its effects, though exhilarating, are unpleasant.

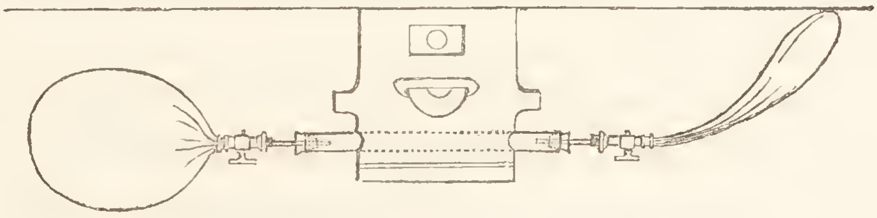
"On the 29th of April I breathed four quarts from and into a silk bag. The pleasant feelings produced at first, urged me to continue the inspiration with great eagerness. These feelings, however, went off towards the end of the experiment, and no other effects followed. The gas had probably been breathed too long, as it would not support flame. I then proposed to Mr. Davy, to inhale the air by the mouth from one bag, and to expire it from the nose into another. This method was pursued with less than three quarts, but the effects were so powerful as to oblige me to take in a little common air occasionally. I soon found my nervous system agitated by the highest sensations of pleasure, which are difficult of description; my muscular powers were very much increased, and I went on breathing with great vehemence, not from a difficulty of inspiration, but from an eager avidity for more air. When the bags were exhausted and taken from me, I continued breathing with the same violence; then suddenly starting from the chair, and vociferating with pleasure, I made towards those that were present, as I wished they should participate in my feelings. I struck gently at Mr. Davy ; and a stranger entering the room at the moment, I made towards him, and gave him several blows, but more in the spirit of good humour than of anger. I then ran through different rooms in the house, and at last returned to the laboratory somewhat more composed; my spirits continued much elevated for some hours after the experiment, and I felt no consequent depression either in the evening or the day following, but slept as soundly as usual."

Dr. Roget states as follows: "The effect of the first inspirations of the nitrous oxide was that of making me vertiginous, and producing a tingling sensation in my hands and feet: as these feelings increased, I seemed to lose the sense of my own weight, and imagined I was sinking into the ground. I then felt a drowsiness gradually steal upon me, and a disinclination to motion: even the actions of inspiring and expiring were not performed without effort; and it also required some attention of mind to keep my nostrils closed with my fingers. I was gradually roused from this torpor by a kind of delirium, which came on so rapidly that the air-bag dropt from my hands. This sensation increased for about a minute after I had ceased to breathe, to a much greater degree than before, and I suddenly lost sight of all the objects around me, they being apparently obscured by clouds, in which were many luminous points, similar to what is often experienced on rising suddenly and stretching out the arms, after sitting long in one position. I felt myself totally incapable of speaking, and for some time lost all consciousness of where I was, or who was near me. My whole frame felt as if violently agitated: I thought I panted violently; my heart seemed to palpitate, and every artery to throb with violence; I felt a singing in my ears; all the vital motions seemed to be irresistibly hurried on, as if their equilibrium had been destroyed, and everything was running headlong into confusion. My ideas succeeded one another with extreme rapidity, thoughts rushed like a torrent through my mind, as if their velocity had been suddenly accelerated by the bursting of a barrier which had before retained them in their natural and equable course. This state of extreme hurry, agitation, and tumult, was but transient. Every unnatural sensation gradually subsided; and in about a quarter of an hour after I had ceased to breathe the gas, I was nearly in the same state in which I had been at the commencement of the experiment. I cannot remember that I experienced the least pleasure from any of these sensations. I can, however, easily conceive, that by frequent repetition I might reconcile myself to them, and possibly even receive pleasure from the same sensations which were then unpleasant. I am sensible that the account I have been able to give of my feelings is very imperfect. For, however calculated their violence and novelty were to leave a lasting impression on the memory, these circumstances were for that very reason unfavourable to accuracy of comparison with sensations already familiar. The nature of the sensations themselves, which bore greater resemblance to a half delirious dream than to any distinct state of mind capable of being accurately remembered, contributes very much to increase the difficulty. And as it is above two months since I made the experiment, many of the minuter circumstances have probably escaped me."

Nitrous oxide is not permanently elastic; for by subjecting it to a pressure of about 50 atmospheres at the temperature of 45°, Mr. Faraday obtained it in the liquid form. It was thus procured by sealing up some nitrate of ammonia in a bent tube and heating it, while the other end was kept cool. Many explosions occurred with very strong tubes, and the experiment is always attended with risk. The tube, when cooled, is found to contain two fluids: the heavier is water, a little acid; the lighter liquid, nitrous oxide; it is limpid, colourless, and so volatile, that the heat of the hand generally makes it disappear in vapour. The application of ice and salt condenses it again. It boils readily by the difference of temperature between 50° and 0°, and does not solidify at 10°. Its refractive power is less than that of any known fluid. A tube being opened in the air, the nitrous oxide immediately burst into vapour. Another tube was opened under water, and the vapour collected and examined proved to be nitrous gas. (*Phil. Trans.* 1823, p. 195.)

Nitrous oxide supports combustion, and a taper introduced into it has its flame much augmented and surrounded by a purplish halo. Phosphorus and sulphur, when introduced in a state of vivid ignition into this gas, are capable of decomposing it, and burn with the same appearance nearly as in oxygen; but, if when put into the gas, they are merely burning dimly, they then do not decompose it and are extinguished, so that they may be melted in the gas, or even touched with a red-hot wire without inflaming. Charcoal, and many of the metals, also decompose nitrous oxide at high temperatures.

At a red heat this gas is decomposed and converted into nitrogen and nitric oxide, undergoing at the same time an increase of bulk. For experiments of this kind the following simple apparatus may be used; it consists of two bladders, one of which is filled with the gas, and the other empty, attached to the extremities of a porcelain tube which traverses the body of a furnace. The bladders are supplied with stopcocks, and the gas is squeezed from one to the other when the tube is red hot.



The best analysis of this gas is effected by detonation with hydrogen; one volume of nitrous oxide requires one volume of hydrogen. This mixture, fired by the electric spark, produces water, and one volume of nitrogen remains. Now, as one volume of hydrogen takes half a volume of oxygen to form water, nitrous oxide must consist of two volumes of nitrogen and one volume of oxygen; these three volumes being so condensed in consequence of chemical union, as only to fill the space of two volumes. The specific gravity of nitrogen, compared with oxygen, is as 14 to 16; nitrous oxide, therefore, consists of

One proportional of nitrogen = 14
One „ oxygen = 8

Equivalent of nitrous oxide = 22

or, $\boxed{\text{Nitrogen } 14}\boxed{\text{Oxygen } 8} = \boxed{\text{Nitrous Oxide } 22}$

Dr. Henry has shown that nitrous oxide forms a combustible mixture with ammonia (*Phil. Trans.*, 1809, p. 444), and that it may be analyzed by detonation over mercury with carbonic oxide. (See Carbonic Oxide.)

Deutoxide of Nitrogen, *Nitric Oxide*, or *Nitrous Gas*, was first procured by Mayo (See *History of Chemistry*); but its properties were first accurately studied by Priestley. It is usually obtained by presenting certain substances to nitric acid, which abstract a portion of its oxygen, leaving the remaining elements in such proportions as to constitute the gas in question; for this purpose some copper filings may be put into a gas bottle with nitric acid diluted with thrice its bulk of water; an action ensues, red fumes are produced, and there is a copious evolution of the gas, which may be collected and preserved over water. The first portions should be rejected, as containing nitrogen and nitrous acid gas. Nitric oxide is presently recognized by the red fumes which it produces when brought into the contact of air.

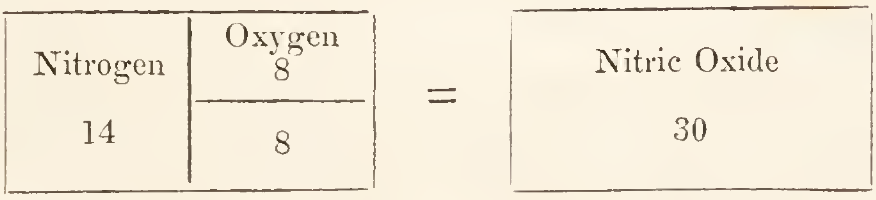
It is a colourless, uncondensible gas: its specific gravity to hydrogen is as 15 to 1. 100 cubic inches weigh 31.770 grains; and compared with air, its specific gravity is as 1.041 to 1000. Under common circumstances it is permanent over water; but if agitated with water previously deprived of air by long boiling, it is dissolved in the proportion of about 1 volume to 20. This solution, when long kept, is found to contain nitrate of ammonia, resulting from the joint decomposition of the nitric oxide and the water.

It is instantly fatal to animals; but as it will always meet with a sufficiency of oxygen in the lungs to convert a part of it into nitrous acid, its abstract effects cannot be determined. An account of an attempt to breathe it will be found in Sir H. Davy's *Researches*, &c., p. 475. When it has been washed with water it is not acid, as may be proved by the colour of litmus remaining unchanged by it. It extinguishes the flame of a taper, and that of sulphur, but phosphorus readily burns in it, if introduced in intense ignition, although it also is extinguished unless it be in vivid combustion. In this case the phosphorus decomposes the gas, nitrogen is evolved, and phosphoric acid formed. Charcoal also decomposes it at a high temperature, the results being carbonic acid and nitrogen.

It is not altered by a red heat, nor does it detonate when mixed with hydrogen, and subjected to the electric spark; a succession of sparks, however, passed through such a mixture, slowly effects the decomposition of a portion of the gas: the same mixture is also decomposed by spongy platinum at common temperatures. When this mixture with hydrogen is kindled by a taper it burns with a green flame. Dr. Henry has shown that nitric oxide detonates with ammonia (*Phil. Trans.*, 1809) in the proportion of 150 measures of the former to 100 of the latter. These gases also slowly act upon each other at common temperatures. Gay Lussac found that in about a month they were reduced to half their joint volume, and that nitrogen was evolved. Some substances which have a strong attraction for oxygen, effect a partial decomposition of the nitric oxide, and convert it, at common temperatures, into nitrous oxide; such, for instance, as moist iron filings, some of the alkaline sulphurets, some of the sulphites; and protomuriate of tin; in which cases two volumes of nitric oxide afford one of nitrous oxide. Nitric oxide may also be decomposed by the action of some of the metals at high temperatures, which absorb its oxygen. Sir H. Davy decomposed it by heated arsenic and by the ignition of charcoal. (*Elements*, 260.) Gay-Lussac decomposed 100 measures of it by the action of heated potassium: 50 measures of pure nitrogen remained, and the loss of weight corresponded to 50 measures of oxygen; so that one volume of nitric oxide is thus resolved into equal volumes of oxygen and nitrogen. If, therefore, we call nitrous oxide a compound of 1 proportional of nitrogen + 1 oxygen, then nitric oxide may be considered as consisting of

One proportional of nitrogen .	. .	=	14
Two proportionals of oxygen .	(8 × 2)	=	16
Equivalent of nitric oxide	. .	=	30

The volumes may be thus represented :—



The most characteristic property of nitric oxide, by which it is immediately distinguished from all other gases, is, that of forming the red fumes of nitrous acid vapour when mixed with oxygen: hence these gases are mutually used to detect each other's presence; and as the nitrous acid is wholly absorbed by water, oxygen may be completely removed from any gaseous mixture containing it in an uncombined state, by the addition of a sufficient quantity of nitric oxide; and, on the other hand, nitric oxide may be removed by the addition of oxygen. Dr. Priestley, who was the first to attempt accurate experiments upon this subject, conceived that the absorption was at all times uniform; but subsequent experiments have shown that it is subject to much variation, more especially dependent upon the presence or absence of water. Although, therefore, nitric oxide may be conveniently used to ascertain the presence of oxygen, it cannot be relied on as an indicator of its proportional quantity; and although Dalton and Gay-Lussac have each proposed methods by which they conceive accuracy may be ensured, they are not such as to admit of general application. The best mode of using the nitric oxide to determine the proportion of oxygen to that of nitrogen in the atmosphere, will be noticed under the head of Atmospheric Air.

Solutions of the protomuriate and protosulphate of iron have the property of absorbing nitric oxide gas: the colour of these solutions is deep olive, and they speedily absorb oxygen when exposed to, or agitated with air, or other mixtures containing it. (See EUDIOMETERS.) This property also enables us to ascertain the purity of nitric oxide, which ought to be wholly absorbed by the solution of iron: some nitrogen or nitrous oxide are thus generally detected in it, and remain perfectly unabsorbed.

Nitric Oxide and Chlorine, when both are perfectly dry, exert no mutual action, but the presence of water causes an immediate change; it is decomposed, and, furnishing oxygen to the nitric oxide, and hydrogen to the chlorine, nitrous acid and muriatic acid gases are generated. It was the presence of water which misled those, who thought that the red fumes produced by mixing nitric oxide and chlorine not carefully dried, resulted from the existence of oxygen in chlorine.

Hyponitrous Acid.—Gay-Lussac has concluded, from his experiments, that there exists a compound of nitrogen and oxygen intermediate between nitric oxide and nitrous acid, which he has termed *pernitrous acid*, but to which the term *hyponitrous acid* is more applicable. He considers it as a compound of 1 proportional of nitrogen = 14, and

3 of oxygen, $(8 \times 3) = 24$: or of 1 volume of nitrogen, and 1.5 of oxygen; accordingly, its equivalent number will be 38. (*Ann. de Chim. et Phys.* i. 399.) He found by mixing nitric oxide and oxygen in tubes standing over mercury, and containing a little concentrated solution of potash, that 400 volumes of nitric oxide were condensed under such circumstances by 100 of oxygen. When, however, he attempted to decompose the salt of potassa thus obtained, nitric oxide was evolved, and nitrous acid formed. The liquid hyponitrous acid, he says, may be obtained by the distillation of nitrate of lead; it passes over in the form of a red vapour, condensable in a receiver surrounded by ice; it evolves nitric oxide when diluted with water; it boils at 80°. There is, however, reason to believe that the compound thus obtained is partly nitrous acid; but considerable difficulty occurs in reconciling the opinions of Gay Lussac and Berzelius upon these acids, the latter chemist applying the term nitrous acid (Salpetrichte Säure) to the pernitrous (hyponitrous) acid of the former.

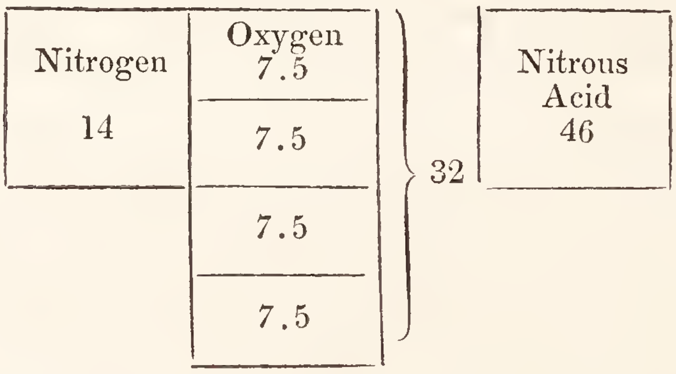
The hyponitrous acid appears to form distinct salts by combining with the salifiable bases. When, for instance, nitrate of potassa or nitrate of baryta are heated, oxygen is evolved, and a soluble hyponitrite remains. When nitric oxide gas is kept for some weeks in contact with a strong solution of potassa, it is partly converted into nitrous oxide, and the solution yields regular crystals of hyponitrite of potassa; for 100 volumes of nitric oxide left 25 of nitrous oxide: the acid, therefore, which was absorbed, consisted of 100 volumes of nitrogen, and 150 of oxygen. According to Berzelius, several of the hyponitrites are best formed by boiling metallic lead in a solution of nitrate of lead, by which a hyponitrite of lead is formed: this salt may then be decomposed by sulphates which form sulphate of lead, and the hyponitrous acid unites to the base of the original sulphate.

When the acid liquid obtained by distilling nitrate of lead is added to sulphuric acid, it forms a peculiar crystallizable compound. Nitric oxide is not of itself absorbed by sulphuric acid.

Nitrous Acid.—This compound is not easily examined, because it is absorbed both by quicksilver and water, so that we are obliged to resort to exhausted glass vessels for its production. When we thus mix two volumes of nitric oxide with one volume of oxygen, much heat is evolved, and the gases become condensed to one-third their original volume, and form *nitrous acid*, or rather vapour, for it is condensed at 0°.

This gas supports the combustion of the taper, of phosphorus, and of charcoal, but extinguishes sulphur. It is readily absorbed by water, forming a sour liquid. Its specific gravity to hydrogen is as 46 to 1; 100 cubic inches weigh 97.428 grains, and, compared with atmospheric air, its specific gravity is as 3.162 to 1000.

It is obvious that this nitrous acid gas must consist of 14 nitrogen + 32 oxygen, and therefore its number is 46; for nitric oxide is composed of equal volumes of nitrogen and oxygen, and one additional volume of oxygen, or two proportionals, by weight, are added to form nitrous acid.



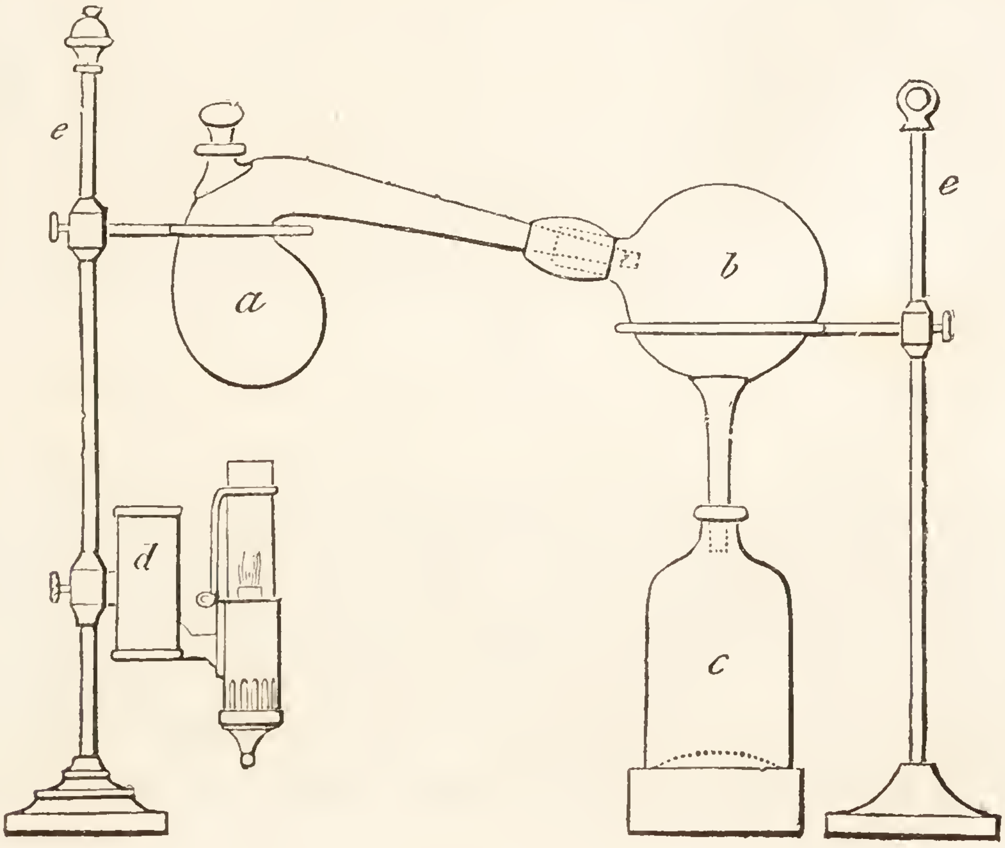
It is commonly stated, that if the mixture of nitric oxide and oxygen be made over water, in the above proportions, in vessels exposing a large surface, and if the gases be perfectly pure, complete absorption takes place; but if either the oxygen or nitric oxide contain uncombined nitrogen, it will remain unabsorbed: when, however, water is admitted to the nitrous acid vapour, formed from its elements, in a dry glass globe, it is dissolved with effervescence, nitric oxide is evolved, and an aqueous solution of nitric and nitrous acids results.

Nitrous acid is absorbed by sulphuric acid, and a crystallized compound is formed, analogous, probably, to that of the hyponitrous acid. It will be more particularly noticed under the article *Sulphuric Acid*.

Nitric Acid.—The fourth compound of nitrogen with oxygen is the nitric acid; the nature of which was first demonstrated by Mr. Cavendish in 1785. (*Phil. Trans.*) It is usually obtained by the distillation of purified nitre with sulphuric acid, of which materials different proportions are employed. The nitric acid of commerce, which is generally red and fuming, in consequence of the presence of nitrous acid, is procured by the distillation of two parts of nitre with one of sulphuric acid; these proportions afford about one part of orange-coloured nitric acid of the specific gravity of 1.48. Upon the large scale 112 lbs. of nitre, and 56 of sulphuric acid, yield from 50 to 52 lbs. of nitric acid. Some manufacturers employ three parts of nitre and two of sulphuric acid, and the *London Pharmacopœia* directs equal weights, by which a nearly colourless nitric acid is afforded, provided the distillation be conducted at as low a temperature as possible.

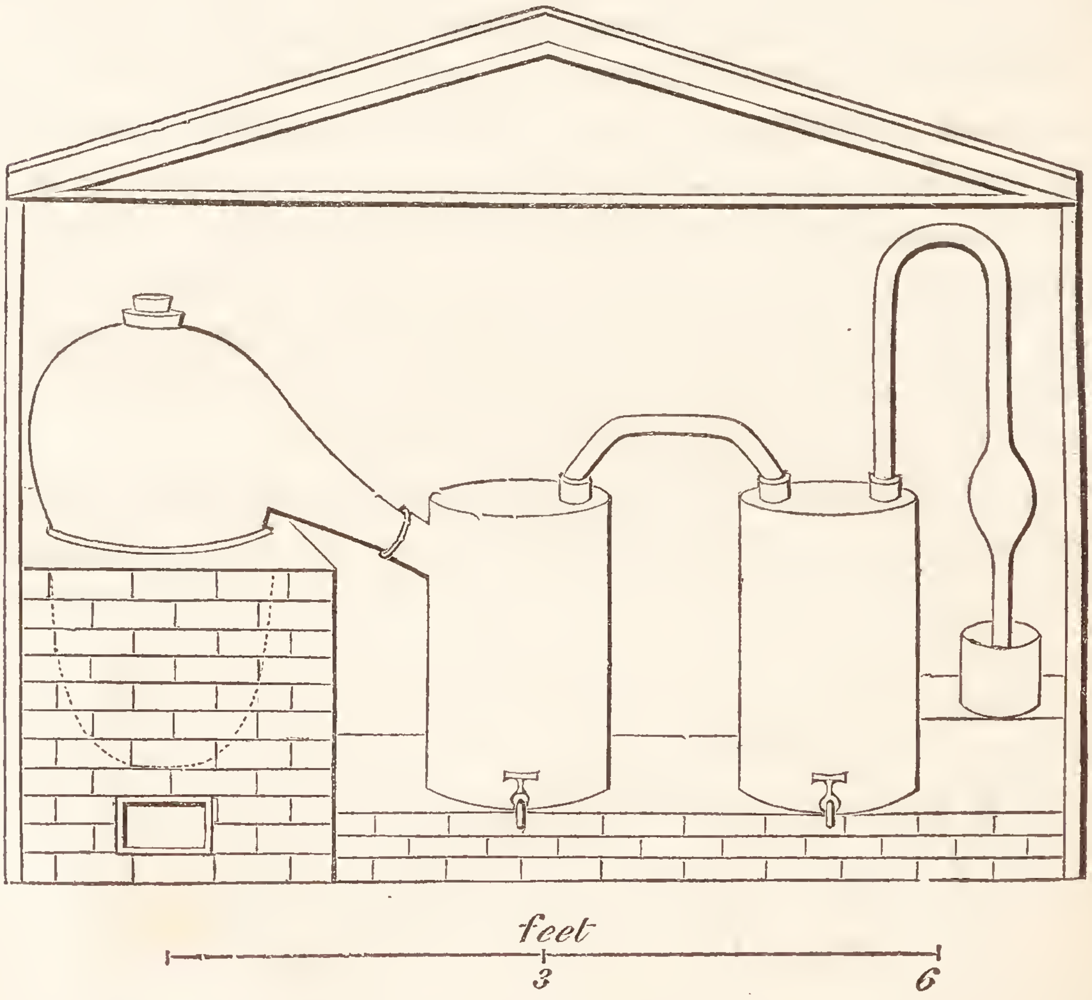
It will appear, by referring to the article *Sulphuric Acid*, that it contains in its liquid state one proportional of dry acid and *one* of water; whereas liquid nitric acid contains one proportional of dry acid, and *two* of water: hence the requisite excess of sulphuric acid, where colourless and perfect nitric acid is to be obtained; hence, too, the red colour of the acid of commerce, in consequence of the smaller quantity of sulphuric acid generally used by the manufacturer, the deficiency of water occasioning the nitric acid to be resolved into nitrous acid and oxygen. This will be more apparent by reference to the article *Bi-sulphate of Potassa.*

The distillation of nitric acid may be conducted upon the small scale in a tubulated glass retort *a*, with a tubulated



receiver *b*, passing into the bottle *c*. The requisite heat is obtained by the lamp *d*, and the whole apparatus supported by the brass stands with sliding rings *e e*. (See the preceding wood-cut.)

But the manufacturer who prepares nitric acid upon a large scale, generally employs distillatory vessels of stone-ware. The following wood-cut represents the arrangement of the distillatory apparatus employed at Apothecary's Hall for the production of common *aquafortis:* it consists of an iron pot, set in brick-work, over a fire-place; an earthen head is luted upon it, communicating with two or more receivers of the same material, furnished with earthenware stop-cocks, the last of which has a tube of safety dipping into a basin of water.



The nitric acid of commerce, as obtained by the above processes, is always impure, and muriatic and sulphuric acids may usually be detected in it. The former may be separated by *nitrate of silver*, and the latter by a very dilute solution of *nitrate of baryta*. To obtain *pure nitric acid*, therefore, add to that of commerce a solution of nitrate of silver as long as it produces any white precipitate; and when this has subsided, pour off the clear liquor, and add, in the same way, the nitrate of baryta; then distil the acid, and it will pass over perfectly pure. For pharmaceutical purposes, the ordinary acid is generally sufficiently pure. If, however, pure nitre and pure sulphuric acid be employed in its production, and the latter not in excess, there is little apprehension of impurity in the resulting acid.

The nitric acid is a colourless liquid, extremely sour and corrosive, and very intense in its action upon the greater number of inflammable bodies, to which it imparts oxygen, and by which it is resolved into some of the inferiorly-oxidized compounds. Its specific gravity, as usually obtained, fluctuates between 1.4 and 1.5, and it always contains water, which modifies its specific gravity. At 247°, when of the specific gravity 1.40, it boils and distils over without change, but the dilute acid is strengthened by boiling. The following table of boiling points has been given by Mr. Dalton.

Acid of specific gravity	1.50	boils at	210°
„	1.45	„	240
„	1.42	„	248
„	1.40	„	247
„	1.35	„	242
„	1.30	„	236
„	1.20	„	226
„	1.15	„	219

At – 40° the concentrated acid congeals. When diluted with half its weight of water it freezes at about 2° below 0°. It absorbs water from the air, and its bulk is thus increased, while its specific gravity is diminished. It is usually coloured by nitrous acid gas, which it evolves when heated, and becomes colourless. It suffers a partial decomposition when exposed to intense light. When diluted with water, the coloured nitric acid assumes various shades of green and blue.

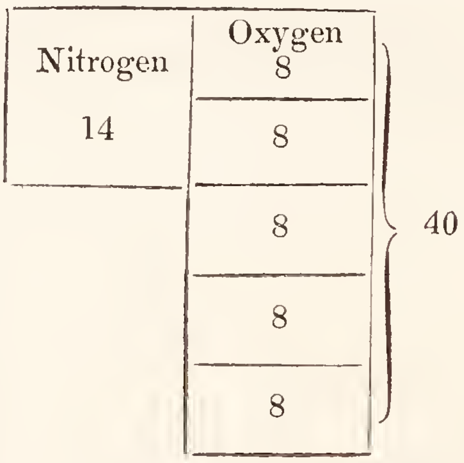
By distilling nitric acid (sp. gr. 1.3) twice successively from four times its weight of sulphuric acid, Gay-Lussac increased its density to 1.510. In this state he found it remarkably susceptible of decomposition by heat or light. (*Annales de Chimie et Phys.* i.)

When nitric acid is mixed with snow the latter is suddenly liquefied, and intense cold is produced. Nitric acid, of the sp. gr. 1.5, mixed with half its bulk of water, occasions an elevation of temperature in the mixture = 112° : 58 parts of the acid with 42 of water, both at 60°, give, on mixture, a temperature of 140°. (*Ure, Quarterly Journal,* iv. 298.)

Nitric acid in its dry state, that is, as it exists combined with metallic oxides in the salts called *nitrates,* may be regarded as composed of

One proportional of nitrogen . . = 14
Five proportionals of ogygen . (8 × 5) = 40
Equivalent of dry nitric acid . . = 54

The following will be the symbol representing its composition :—



Consequently, the representative number of *dry* nitric acid is 54. But in its liquid state it always contains water ; and when in this state its specific gravity is 1.5, it may be regarded as a compound of one proportional of dry acid and two of water, which may be numerically expressed thus :—

Acid Water
54 + 18 = 72 liquid acid.

The following Table drawn up by Dr. Ure, exhibits the quantity of dry acid and of liquid acid (sp. gr. 1.5) at different densities :—*Quarterly Journal,* iv. 297, and *Dictionary,* p. 71, 2nd Ed.

TABLE OF NITRIC ACID BY Dr. URE.

Specific gravity.	Liquid Acid in 100.	Dry acid in 100.	Specific gravity.	Liquid Acid in 100.	Dry Acid in 100.	Specific gravity.	Liquid Acid in 100.	Dry acid in 100.
1.5000	100	79.700	1.3783	66	52.602	1.1895	33	26.301
1.4980	99	78.903	1.3732	65	51.805	1.1833	32	25.504
1 4960	98	78.106	1.3681	64	51.068	1.1770	31	24.707
1.4940	97	77.309	1.3630	63	50.211	1.1709	30	23.900
1.4910	96	76.512	1.3579	62	49.414	1.1648	29	23.113
1.4880	95	75.715	1.3529	61	48.617	1.1587	28	22.316
1.4850	94	74.918	1.3477	60	47.820	1.1426	27	21.519
1.4820	93	74.121	1.3427	59	47.023	1.1465	26	20.722
1.4790	92	73.324	1.3376	58	46.226	1.1403	25	19.925
1.4760	91	72.527	1.3323	57	45.429	1.1345	24	19.128
1.4730	90	71.730	1.3270	56	44.632	1.1286	23	18.331
1.4700	89	70.933	1.3216	55	43.835	1.2217	22	17.534
1.4670	88	70.136	1.3163	54	43.038	1.1168	21	16.737
1.4640	87	69.339	1.3110	53	42.241	1.1109	20	15.940
1.4600	86	68.542	1.3056	52	41.444	1.1051	19	15.143
1.4570	85	67.745	1.3001	51	40.647	1.0993	18	14.346
1.4530	84	66.948	1.2947	50	39.850	1.0935	17	13.549
1.4500	83	66.155	1.2887	49	39.053	1.0878	16	12.752
1.4460	82	65.354	1.2826	48	38.256	1.0821	15	11.955
1.4424	81	64.557	1.2765	47	37.459	1.0764	14	11.158
1.4385	80	63.760	1.2705	46	36.662	1.0708	13	10.361
1.4346	79	62.963	1.2644	45	35.865	1.0651	12	9.564
1.4306	78	62.166	1.2583	44	35.068	1.0595	11	8.767
1.4269	77	61.369	1.2523	43	34.271	1.0540	10	7.970
1.4228	76	60.572	1.2462	42	33.474	1.0485	9	7.173
1.4189	75	59.775	1.2402	41	32.677	1.0430	8	6.376
1.4147	74	58.978	1.2341	40	31.880	1.0375	7	5.579
1.4107	73	58.181	1.2277	39	31.083	1.0320	6	4.782
1.4065	72	57.384	1.2212	38	30.286	1.0267	5	3.985
1.4023	71	56.587	1.2148	37	29.489	1.0212	4	3.188
1.3978	70	55.790	1.2084	36	28.692	1.0159	3	2.391
1.3945	69	54.993	1.2019	35	27.895	1.0106	2	1.594
1.3882	68	54.196	1.1958	34	27.098	1.0053	1	0.797
1.3833	67	53.399						

The column of dry acid shows the weight which any salifiable base would gain by uniting with 100 parts of the liquid acid of the corresponding specific gravity.

Nitric acid may be decomposed by passing its vapour through a red-hot porcelain tube; oxygen is given off, nitrous acid gas is produced, and a quantity of diluted acid passes over into the receiver, having escaped decomposition; so that it is thus proved to consist of nitrous acid gas, oxygen, and water.

For experiments of this kind, the form of apparatus described for the decomposition of water by iron may be employed, omitting the condensing worm-pipe.

When nitric oxide is passed through concentrated nitric acid it is decomposed, and nitrous acid is formed partly by the acquisition of oxygen, by the oxide, and partly by its loss by the acid. "The nitrous acid thus derived from two sources gives a colour to the nitric acid, the depth and kind of which depend upon the quantity of the deutoxide of nitrogen which has been employed. The first portion communicates a pale straw colour, which gradually deepens as the absorption of the deutoxide continues, till the nitric acid has acquired a deep orange hue, together with all the characters of strong fuming nitrous acid. But the solution still continues to absorb the deutoxide, and, in doing so, its colour passes through different shades of olive and green, till it becomes greenish-blue. By applying heat to the blue liquid, the deutoxide of nitrogen is evolved, and in proportion as it escapes, the colour of the solution changes to green, olive, orange, and yellow; at length becoming pale as at first. Nitrous acid vapours are likewise disengaged as well as the deutoxide. These phenomena are very favourable to the view that the conversion of the orange colour into olive, green, and blue, is owing to the formation of hyponitrous acid."—TURNER, p. 231.

The facility with which nitric acid imparts oxygen, renders it a valuable oxydizing agent in many chemical operations: phosphorus and most of the metals decompose it at common temperatures, and sulphur and carbon when aided by heat. It acts energetically, often when diluted, upon the greater number of animal and vegetable substances, and mutual decompositions ensue. A drachm of oil of turpentine mixed with half a drachm of sulphuric acid, instantly bursts into flame upon the addition of a drachm of nitric acid. A piece of glowing charcoal thrown upon the surface of the concentrated acid, burns vehemently with the evolution of red fumes (Berzelius). Oxalic, malic, and carbonic acids are the common products of the action of dilute nitric acid upon most vegetable and animal substances: fatty matter, ammonia, and hydrocyanic acid are also sometimes formed. It stains the greater number of animal substances of a yellow colour, and is hence used in the production of yellow patterns upon coloured woollen goods: it is used in fumigations to destroy contagious and infectious matter, more especially in inhabited apartments, where chlorine would prove injurious. For this purpose nitrate of potassa and sulphuric acid are mixed in a saucer, and the evolution of the acid vapour aided by a gentle heat. In pharmacy and a variety of other processes, it is susceptible of interesting applications: it is used for etching on copper, and as a solvent for tin in the preparation of valuable mordants used by dyers and calico-printers: it is an important agent in metallurgy, and especially in the art of assaying. In medicine it is prescribed as a tonic, and occasionally in syphilitic, hepatic, and eruptive disorders.

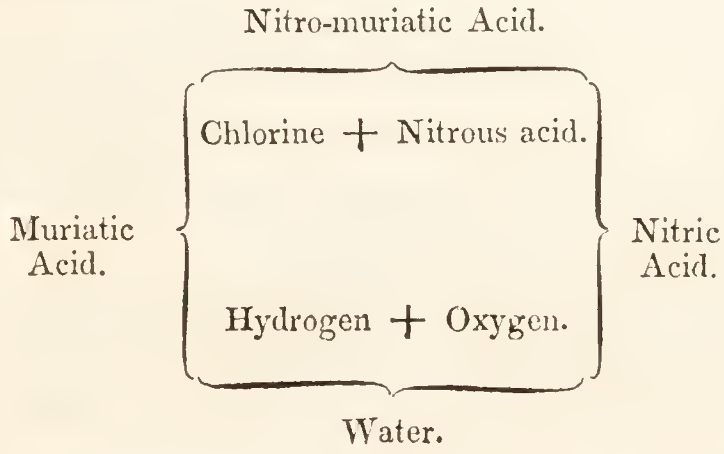
The salts which nitric acid forms, and which are termed *nitrates*, are all soluble in water; and hence neither its presence nor quantity can be determined by any precipitating re-agent. When uncombined, it is easily recognized by the facility with which it attacks copper, causing the evolution of nitric oxide, and affording a blue solution; and by the formation of nitre when it is saturated with potassa, which salt readily crystallizes in six-sided prisms. When muriatic acid is added to a solution of a nitrate, chlorine is evolved, and the liquid acquires the power of dissolving gold leaf; but as the action of muriatic acid on the salts of chloric and bromic acids also furnishes a solution which dissolves gold, no inference can be drawn from the experiment, except the absence of these acids has been previously ascertained. (Turner.) The following method of detecting the presence of nitric acid has been suggested by Dr. Liebig, who says that it is effective when not more than a four-hundredth part of the acid is present. The liquid to be examined must be mixed with sufficient sulphuric solution of indigo, to acquire a distinct blue colour; a few drops of concentrated sulphuric acid are then added, and the whole boiled; if the liquid contain a nitrate, it will either be bleached or rendered yellow. By adding a little common salt to the liquid before applying heat, a five-hundredth part of nitric acid may easily be discovered. (*Ann. de Chim. et Phys.* xxxv. 80.)

M. Runge proposes to detect nitric acid and its combinations as follows:—"Pour a solution of proto-muriate of iron upon the surface of an amalgam of zinc, and then place a crystal of nitre on the latter in the fluid: a dark band immediately forms around the crystal, sometimes extending over the whole surface of the amalgam. All the nitrates, as well as nitric acid, act in this manner; but other salts, such, for instance, as the chlorates, produce no such effect, so that a very sensible test of the presence of nitric acid is thus afforded. It is necessary that the solution employed be a proto-salt of iron. If nitric acid is supposed to exist in a liquid, it should be saturated with potassa evaporated to dryness, and the dry mass tried. Salts of copper and silver must not be present. (*Annalen der Physik.* 1827.)

Nitric acid is an important agent in the operations of analysis. It is used—1. to oxydize and dissolve the metals, and to separate them from the few which are not acted upon by it, especially gold and platinum: it is of constant use in the process of assaying for separating silver from gold. 2. To separate certain metals in the form of insoluble peroxides, such as antimony and tin, from those which yield soluble oxides; as in the separation of tin from mercury: it also is useful in the peroxydizement of iron and manganese, by which those metals are rendered insoluble in nitric acid, and thus separable from soluble earths, &c. 3. Dilute nitric acid separates sulphur from the metals in the form of an insoluble magma or grey powder, as in the analysis of sulphuret of copper, of lead, of silver; if concentrated, it acidifies sulphur and arsenic. 4. The concentrated acid detects sulphuretted hydrogen by the production of a white cloud, and the destruction of its fetid odour. 5. It is used as a solvent to determine the nature of certain precipitates, and to separate the soluble from the insoluble. The precipitates formed by the vegetable acids, by succinic acid, by phosphoric acid, and by arsenic acid in the solutions of baryta, of lime, and of lead, are easily soluble in dilute nitric acid; but the precipitate by sulphuric acid in solutions of baryta is perfectly insoluble, and that in solution of lead difficultly soluble, requiring about 100 parts of the acid. 6. Nitric acid is a test of certain organic substances: it generally tinges those containing nitrogen of a yellow colour; it detects strychnia, by rendering it red; the nitric solution of uric acid leaves a red residue on evaporation; it changes polychroite to green, and guaiacum to blue and green. It distinguishes gum from starch, by converting the former into mucous or saclactic acid: cork it converts into suberic acid. 7. Many of the nitrates, and the nitro-muriatic acid, are used as tests. (Pfaff. Handbuch *der Analytischen Chemie*, i. 98, 2nd Ed.)

The nature of nitric acid was first synthetically demonstrated by Mr. Cavendish, who passed electric sparks through a portion of atmospheric air, or through a mixture of one part of nitrogen and two of oxygen, confined over mercury. After some time the mixture diminished in bulk, and, on admitting a little water, an acid solution was obtained, which afforded crystals of nitre when saturated with potassa.

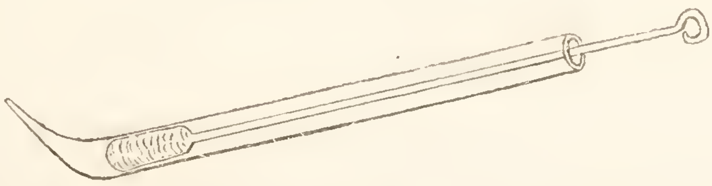
Nitro-muriatic Acid.—This term has been applied to the *Aqua Regia* of the alchemists. When nitric and muriatic acids are mixed, they become yellow, and acquire the power of readily dissolving gold, which neither of the acids possessed separately. This mixture evolves chlorine, a partial decomposition of both acids having taken place, and water, chlorine, and nitrous acid are thus produced; that is, the hydrogen of the muriatic acid abstracts oxygen from the nitric to form water: the result must be chlorine and nitrous acid.—Davy, *Journal of Science and the Arts*, vol. i. p. 67. The following diagram may, perhaps, serve to render these mutual changes more evident:—



Two parts of muriatic acid and one of nitric acid furnish the most effective mixture; but a solution having the same general properties is obtained by adding nitre to muriatic acid, or common salt to nitric acid. According to Berzelius, the mutual decomposition of the two acids proceeds only so far in the first instance as to saturate the liquid with chlorine; but when heat is applied, chlorine is evolved till one of the acids is entirely decomposed. When a metal is put into nitro-muriatic acid, it absorbs the chlorine, and is dissolved; for the liquid cannot become then saturated with chlorine, because the metal combines with it as fast as it is evolved: the application of heat greatly accelerates this action, but much chlorine may be lost by employing too high a temperature. As nitric oxide is evolved during the solution of a metal in nitro-muriatic acid, it might be supposed that the hydrogen of the muriatic acid had reduced the nitric acid to the state of nitric oxide; but Davy has shown that a mixture of muriatic and *nitrous* acids possesses none of the properties of Aqua Regia: consequently, the evolution of nitric oxide depends upon the spontaneous resolution of the produced nitrous acid into nitric acid and nitric oxide. Nitro-muriatic acid is the common solvent of gold and platinum, and may, with proper precautions, be used in the separation of those metals from silver, which remains as an insoluble chloride. It furnishes a useful solution of tin, and is employed in the analysis of minerals containing sulphur, to separate and acidify that elementary body.

Nitrogen and Chlorine—Chloride of Nitrogen.—These gases do not unite *directly*, but the compound may be obtained by exposing a solution of *nitrate* or *muriate of ammonia* to the action of chlorine, at a temperature of 60° or 70°. The gas is absorbed, and an oil-like fluid, heavier than water, is produced by the union of the nascent nitrogen evolved in the decomposition of the ammonia of the salt, with the chlorine. It was discovered by M. Dulong, in 1812.—*Annales de Chimie*, vol. lxxxv.; and its properties afterwards investigated by Sir H. Davy. (*Phil. Trans.*)

The simplest mode of obtaining this compound, consists in filling a perfectly clean glass basin with a solution of about one part of sal-ammoniac in twelve of water, and inverting into it a tall jar of chlorine. The saline solution is gradually absorbed, and rises into the jar, a film forms upon its surface, and it acquires a deep yellow colour; at length small globules, looking like yellow oil, collect upon its surface, and successively fall into the basin beneath, whence they are most conveniently removed by drawing them into a small and perfectly clean glass syringe, made of a glass tube drawn to a pointed orifice, and having a copper wire with a piece of clean tow wrapped round it for a piston; in this way a globule may be drawn into the tube, and transferred to any other vessel.



Its specific gravity is 1.6; it is not congealed by cold. Its odour is irritating and peculiar; it very soon evaporates when exposed to air. This substance is dangerously explosive, and is decomposed with violent detonation by many combustibles, especially phosphorus and fixed oils. In making these experiments, which should be conducted with extreme caution, and the face protected by a mask (Dulong lost an eye and the use of a finger, and Sir H. Davy was wounded in the face by the effects of its detonation), a small globule of the compound, about the size of a mustard-seed, may be cautiously transferred to a clean porcelain basin, half filled with water, and placed under a wire cage: a very small piece of phosphorus, fixed to the end of a long stick, or a long rod with the extremity dipped in oil, may be then brought into contact with the globule, which instantly explodes with a flash of light, dispersing the water, and breaking the basin to atoms. At 160° it distils without change, but at 212° it explodes, and is decomposed. It was submitted to the action of 125 different substances, by Messrs. Porret and Wilson, of which the following caused it to explode.

Phosphorus.
Phosphuret of lime.
Caoutchouc.
Myrrh.
Palm-oil.
Ambergris.

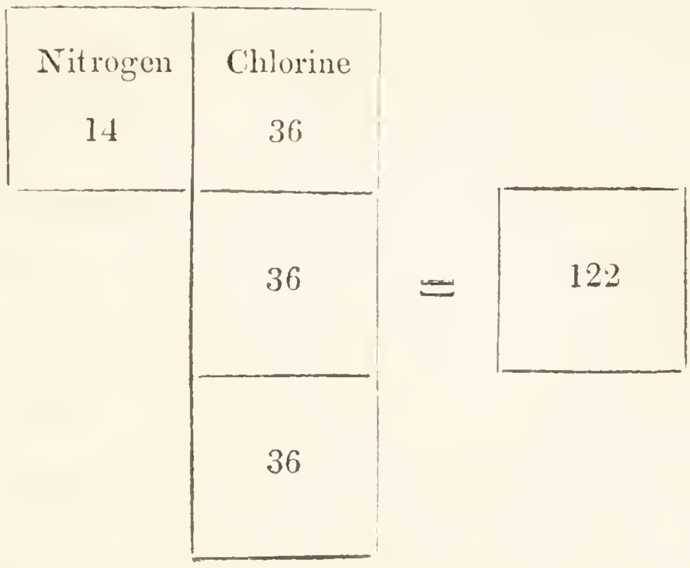
Whale-oil.
Linseed-oil.
Olive-oil.
Camphorated oil.
Sulphuretted oil.
Oil of turpentine.
Oil of tar.
Oil of amber.
Oil of orange-peel.
Naphtha.
Strong liquid ammonia.
Fused potassa.
Phosphuretted hydrogen.
Nitric oxide.
Metallic soaps.

The metals, resins, and sugar did not cause it to explode. —Nicholson's *Journal*, vol. xxxiv. Alcohol quietly changes it into a white substance. Mercury and most of the other metals absorb the chlorine, and evolve nitrogen. It gradually disappears when kept in a stopped phial with water, and nitrous and muriatic acid are formed by the mutual decomposition of the liquids. In concentrated muriatic acid it forms ammonia, and chlorine is evolved. It is also slowly decomposed by dilute liquid ammonia; muriate of ammonia is formed, and nitrogen evolved.

The existence of nitrogen in nearly all the powerfully detonating bodies is a singular fact, and the decomposition of this compound is attended by a circumstance observed in a few other cases only, namely, the appearance of flame or fire, which is generally the result of condensation and union, but here is accompanied by expansion and decomposition; by the separation of two bodies previously combined: the decomposition of the oxides of chlorine already referred to, and that of iodide of nitrogen and of peroxide of hydrogen (oxygenated water) exhibits the same peculiarity. Until the cause of the singularly powerful detonating qualities of such compounds is ascertained, these phenomena must remain unexplained, and at variance with our usual explanations of the cause of the evolution of heat and light.

Chloride of nitrogen yields, by decomposition, 1 volume of nitrogen and 3 of chlorine; and as the specific gravity of nitrogen to chlorine is as 14 to 36, so it may be said to consist of

1 proportional of nitrogen + 3 proportionals of chlorine, or 14 nitrogen + 108 chlorine by weight, and its number will be 122.

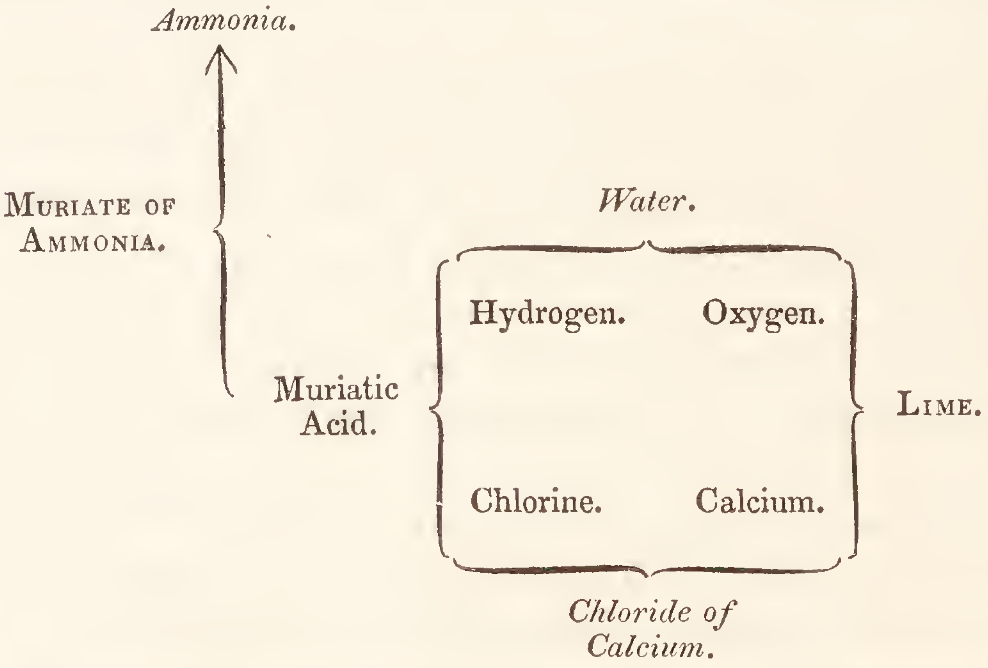


In the state of vapour, it is probable that the four volumes of aëriform matter which it affords by decomposition, are condensed into one, since its decomposition by mercury is not attended by any change of its volume.

Nitrogen and Iodine.—A compound of these bodies may be procured by pouring a solution of ammonia upon a very small quantity of iodine. The iodine decomposes part of the ammonia, and, combining with its hydrogen, forms hydriodic acid, and this, uniting with the ammonia, forms hydriodate of ammonia: the nascent nitrogen unites with another portion of iodine, and forms an insoluble black powder, which may be collected by pouring off the liquid, and placing it, while moist, in small parcels upon bibulous paper, where it must be suffered to dry spontaneously. It detonates upon the slightest touch, and the detonation of one portion generally causes the neighbouring ones to explode also; it even explodes whilst moist, if rubbed or pressed. When it detonates, the purple fumes of iodine are perceptible. When left exposed to air it slowly evaporates; and if moist, is gradually resolved into nitrogen and iodic and hydriodic acids. It is decomposed by hot water and by alkaline solutions. From Gay-Lussac and Colin's researches, this compound appears to consist of 3 proportionals of iodine + 1 of nitrogen; or

Iodine	125 × 3 =	375
Nitrogen	. .	14
		389

Nitrogen and Hydrogen.—When nitrogen and hydrogen gases are mixed, they show no tendency to combine; they unite, however, under certain peculiar circumstances of evolution, and the result is *Ammonia*, or *Volatile Alkali*. This gaseous compound may be obtained by heating a mixture of *quicklime* and *muriate of ammonia*. Two parts of dry quicklime and one of muriate of ammonia may be introduced into a small glass retort, and, upon the application of a gentle heat, the gas is evolved. It must be collected over mercury. Towards the latter part of the operation water passes over, which may be arrested in the neck of the retort by the previous introduction of a piece of blotting-paper. The theory of the decomposition which here ensues is somewhat complicated, and will be better understood when the nature of lime is explained. Muriate of ammonia is a compound of muriatic acid and ammonia; by the action of the lime (which is an oxide of calcium) the ammonia is expelled in its pure and gaseous form: the muriatic acid and the lime then mutually decompose each other, and water and chloride of calcium are the results. The following diagram may, perhaps, more clearly explain this:—



In this Table the original substances are printed in small capitals, the products in Italics, and the components in common type.

Ammonia is permanently elastic at common temperatures; by exposing it to intense cold, Guyton supposed that he had observed it to assume a liquid form. (*Ann. de Chim.* xxix. 290.) But this could not be the case, as it requires for its liquefaction a pressure of 6.5 atmospheres at the temperature of 50°. (Faraday, *Phil. Trans.* 1823, p. 196.) It was most readily obtained in this state by disengaging it in a sealed tube from chloride of silver, which had been previously made to absorb it. It was colourless, transparent, of a specific gravity of 0.76, and its refractive power surpassed that of water.

Ammonia is very pungent and acrid, but when diluted by mixture with common air, agreeably stimulant. It converts most vegetable blues to green, and the yellows to red, properties which belong to the bodies called *alkalis*. Ammonia, therefore, has been termed *volatile alkali;* and the change of colour thus effected by it, is distinguished from that produced by the *fixed* alkalis, by the return of the original tint, when the ammonia flies off by exposure. It saturates the acids, and produces an important class of *ammoniacal salts*, which are recognized by the evolution of ammonia when they are triturated with potassa, soda, or lime.

Its specific gravity to hydrogen is as 8.5 to 1; compared with air it is as 0.590 to 1; 100 cubical inches weigh 18 grains. It extinguishes flame, but forms a difficultly inflammable mixture with common air and with oxygen, and may be burned when issuing from a capillary orifice in an atmosphere of oxygen. Ammonia is abundantly absorbed by chloride of calcium, as well as by several other chlorides: if, therefore, it be required artificially to dry the gas, potassa or lime should be used. (*Quarterly Journal*, v. 74.)

Water, at the temperature of 50°, takes up 670 times its volume of ammonia; its bulk is increased, and its specific gravity diminished; that of a saturated solution is 0.875, water being 1.000. The following table shows the quantity of ammonia in solutions of different specific gravities.—Davy's *Chem. Phil.* p. 268.

100 Parts of Sp. Gr.		Of Ammonia.	100 Parts of Sp. Gr.		Of Ammonia.
8750*	contain	32.50	9435	contain	14.53
8875	„	29.25	9476	„	13.46
9000	„	26.00	9513	„	12.40
9054*	„	25.37	9545	„	11.56
9166	„	22.07	9573	„	10.82
9255	„	19.54	9597	„	10.17
9326	„	17.52	9619	„	9.60
9385	„	15.88	9692*	„	9.50

The usual state in which ammonia is employed is in solution, both in chemistry and medicine. This solution bears

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* The three results marked by the asterisk were gained by experiments; the other numbers by calculation.

the name of *Liquor Ammoniæ* in the *London Pharmacopœia*. It may be obtained by passing the gas into water in a proper apparatus, or by distilling over the water and gas together.

The following process, recommended by Mr. R. Phillips, answers well. On 9 ounces of well-burned lime pour half a pint of water, and when it has remained in a well-closed vessel for about an hour, add 12 ounces of muriate of ammonia in powder and three pints and a half of boiling water; when the mixture has cooled, pour off the clear portion, and distil from a retort 20 fluid ounces. The specific gravity of this solution, which is sufficiently strong for most purposes, is 0.954.—*Remarks on London Pharmacopœia*, p. 34.

The specific gravity of the officinal solution directed in the *Pharmacopœia*, is 0.960.

Liquid ammonia should be preserved in well-stopped glass bottles, since it loses ammonia and absorbs carbonic acid, when exposed to air. When heated to about 140°, ammonia is rapidly given off by it; when concentrated it requires to be cooled to 40° before it congeals, and then it is apparently inodorous, and of a gelatinous appearance.

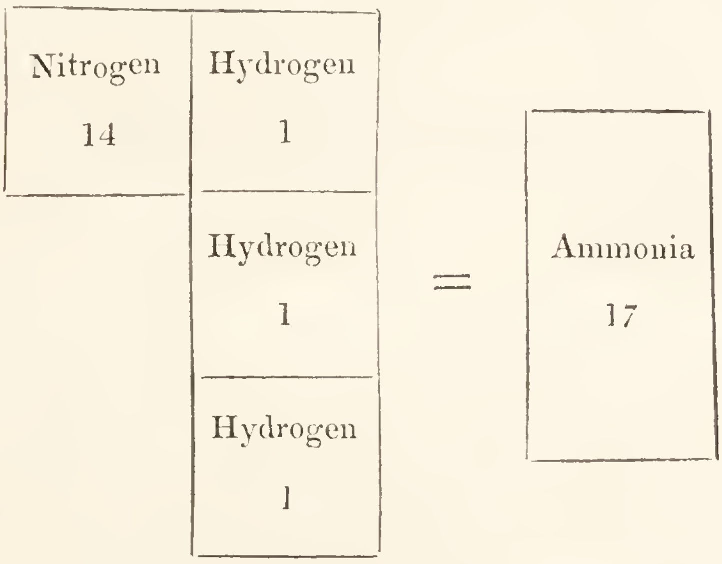
If a piece of ice be introduced into a jar of ammonia standing over quicksilver, it melts with great rapidity, and liquid ammonia is produced.

Dr. Henry (*Phil. Trans.* 1809) first observed that a mixture of ammonia and oxygen gas might be fired by an electric spark, and this property furnishes a means of analyzing the alkaline gas. Electricity also decomposes ammoniacal gas. If a succession of electrical sparks be passed through a small portion of the gas confined in a proper tube over quicksilver, it will increase to about twice its original bulk, and lose its easy solubility in water. If the gas thus expanded be mixed with from one-third to one-half its bulk of oxygen, and an electric spark passed through the mixture, an explosion takes place, attended by considerable diminution. Note the amount of the diminution, divide it by 3, and multiply the product by 2. The result shows the quantity of hydrogen; for 2 measures of hydrogen are saturated by 1 of oxygen. Thus, suppose 10 measures of ammonia, expanded by electricity to 18, and that, after adding 8 measures of oxygen gas, we find the whole (= 26 measures) reduced by firing to 6 measures, the diminution will be 20. Then 20 ÷ 3 = 6.66 and 6.66 × 2 = 13.32 measures of hydrogen gas from 10 of ammonia; and 18 — 13.32 = 4.68 for the nitrogen gas contained in the product of electrization. Therefore, 10 measures of ammonia have been destroyed and expanded into

13.32 measures of hydrogen gas.
4.68 „ nitrogen gas.

—Henry's *Elements*, 7th Ed. vol. i. p. 233.

It appears probable from the above, and from the prior experiments of A. Berthollet, that one volume of ammonia is resolved by decomposition into two volumes of a mixture of hydrogen and nitrogen, consisting of three volumes of hydrogen and one volume of nitrogen; hence the following symbols will represent the composition and volume of ammonia:—



In reference to this result, Dr. Turner observes (*Elements*, 2nd Ed. p. 234), that since

150 cubic inches of hydrogen weigh	3.177	grains
50 „ of nitrogen „	14.826	
100 cubic inches of ammonia must weigh	18.003	

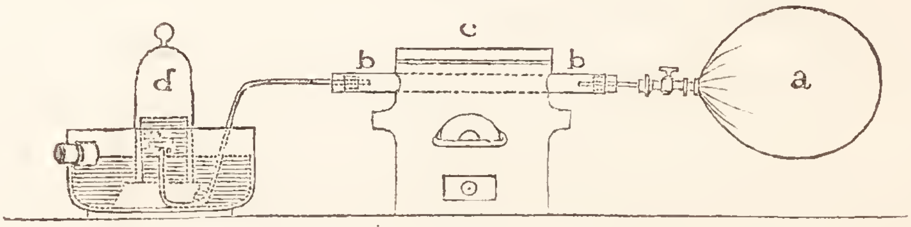
and it is composed by weight of

Hydrogen	3.177	3 or 3 proportionals
Nitrogen	14.826	14 or 1 proportional.

The specific gravity of ammonia, according to this calculation, is 0.5902.

When ammonia is detonated with excess of oxygen, a portion of nitric acid seems always to be formed: indeed, according to Bischof, this acid is more or less formed in all cases of its combustion with oxygen. He found the limits of combustibility with oxygen to be, on the one hand, 1 ammonia and 0.6 oxygen; and, on the other, 1 and 3.17 by volume.

Ammonia is decomposed by passing it through a red-hot porcelain tube. If passed over a coil of iron or copper wire in a red-hot porcelain tube, the metals become brittle, but their weight is not altered. According to Thenard, when any of the five following metals are inclosed in the tube, they promote the decomposition of ammonia at a temperature below that which it requires *per se;* in the following order: iron, copper, silver, gold, platinum. In all these cases the gas suffers expansion, and is resolved into hydrogen and nitrogen gases, furnishing a singular instance of change of properties in consequence of chemical combination. *a* is a bladder filled with ammonia, which may be passed through the iron tube *b*, placed in the furnace *c*; the gas is decomposed, and hydrogen and nitrogen may be collected over the water in *d*.



Ammonia is also decomposed when passed over black oxide of manganese, heated red-hot in a porcelain tube; the results are water and nitrous acid gas; nitrate of ammonia is also often formed. Passed through a porcelain tube containing red-hot charcoal, ammonia forms a portion of hydrocyanic acid.

Ammonia is produced synthetically during the decomposition of many animal substances; it is also formed during the violent action of nitric acid upon phosphorus, and some of the metals; and by moistened iron filings exposed to an atmosphere of nitrogen: in these cases the nascent gases unite so as to form a portion of ammonia. There are some other anomalous cases of its evolution and apparent production, which are not easily explained, but which have been enumerated and commented upon by Mr. Faraday, in a paper published in the *Quarterly Journal* (vol. xix. p. 16).

Ammonia combines with the acids, and produces a class of salts which, with very few exceptions, are soluble in water, and which evolve the odour of ammonia when mixed with lime or with pure potassa. These salts are, for the most part, entirely dissipated, and, generally speaking, decomposed by heat. Ammonia mixed with the gaseous acids condenses them into white pulverulent compounds; it combines either with half its volume, or with an equal volume, or with two volumes of the acid. The same combination ensues when the volatile acids are brought near free ammonia; and in this way very minute quantities of ammonia may be discovered, by dipping a glass rod into muriatic, nitric, or acetic acid, and bringing near any liquid or substance supposed to evolve ammonia, which will be immediately recognised by white fumes.

Ammonia and Chlorine.—When these gases are mixed, a partial decomposition of the former ensues. On mixing 15 parts of chlorine and 40 of ammonia, 5 parts of nitrogen are liberated, and muriate of ammonia is formed. If the gases be perfectly dry, considerable heat is evolved, and a flame is perceived to traverse the vessel in which the experiment is made. When solutions of chlorine and ammonia are mixed, an effervescence ensues, nitrogen gas is evolved, and muriate of ammonia formed; and when gaseous chlorine is transmitted in successive bubbles into a strong solution of ammonia, each produces a slight explosion attended by a flash of light (See Nitrogen).

Ammonia and Chloric Acid.—*Chlorate of Ammonia* is formed by saturating chloric acid with carbonate of ammonia. It forms very soluble acicular crystals, of a sharp taste, which detonate when thrown upon hot coals. It probably consists of 1 proportional of each of its components, or 17 ammonia + 76 chloric acid; but its composition has not been experimentally determined. (Vauquelin, *Ann. de Chim.* xcv. 97.)

Ammonia and Muriatic Acid—Muriate of Ammonia—Hydrochlorate of Ammonia—Sal Ammoniac.—This salt may be produced directly by mixing equal volumes of ammonia and muriatic acid, when an entire condension ensues.

The specific gravity of ammonia to muriatic acid is as 17 to 37; therefore, dry muriate of ammonia consists of 37, muriatic acid + 17 ammonia, and its representative number is 54.

17 Ammonia.	37 Muriatic Acid.

= 54.

In its usual state, Berzelius says that it contains one proportional of water, and is, therefore, a compound of

Dry muriate of ammonia . .	54
Water . . .	9
	63

Muriate of ammonia was formerly imported from Egypt, where it was obtained by burning the dung of camels; it is now abundantly prepared on the Continent and in this country. Its preparation will be hereafter described. When obtained by evaporation from its solution in water, it forms octoëdral, prismatic, and plumose crystals; but, in commerce, it usually occurs, as procured by sublimation, in white cakes, hard, and somewhat elastic, and very slightly deliquescent: in this compact state it requires for solution 3.25 parts of water at 60°, cold being produced during its solution; it also dissolves in alcohol: when heated it sublimes without decomposition in the form of white vapour, and may be even passed through a red-hot porcelain tube without change. It is, however, decomposed when transmitted over ignited iron or copper wire.

Sal-ammoniac is used in the arts for a variety of purposes, especially in certain metallurgic operations. It is used in tinning, to prevent the oxidation of the surface of copper; and small quantities are consumed by dyers. Dissolved in nitric acid, it forms the *Aqua Regia* of commerce, used for dissolving gold, instead of a mixture of nitric and muriatic acids. It is decomposed by the fixed alkalis, and by the alkaline earths.

Native Muriate of Ammonia occurs massive and crystallized, in the vicinity of volcanoes, and in the cracks and pores of lava near their craters. It has thus been found at Etna, and at Vesuvius, in the Solfaterra near Naples, and in some of the Tuscan lakes. An efflorescence of native sal-ammoniac is sometimes seen upon pit-coal. Its colour varies from the admixture of foreign matter, and it is frequently yellow from the presence of sulphur. It is said that considerable quantities of native sal-ammoniac are also found in the country of Bucharia, where it occurs with sulphur in rocks of indurated clay. The ancients, according to Pliny, called this salt *ammoniac*, because it was found near the temple of Jupiter

Ammon, in Africa. It has been detected by Dr. Marcet in sea-water. (*Phil. Trans.* 1822, p. 454.)

Ammonia and Iodine.—Iodine absorbs dry ammoniacal gas, and produces a viscid compound, at first of a metallic appearance, but becoming deep-brown by excess of ammonia. The action of iodine on liquid ammonia has been already described (page 217).

Iodate of Ammonia is formed by saturating iodic acid or chloriodic acid with ammonia. It forms small crystals sparingly soluble in water, and deflagrates, when thrown upon hot coals, with a pale violet flame; heated highly in a tube it explodes, and is decomposed into oxygen, nitrogen, water, and iodine. Its composition has not been ascertained.

Hydriodate of Ammonia.—In a former paragraph the action of iodine on ammonia has been stated to produce a portion of hydriodate of ammonia: this compound may be directly formed by mixing equal volumes of hydriodic and ammoniacal gases; or by saturating liquid hydriodic acid by carbonate of ammonia: it forms very soluble and deliquescent cubic crystals, volatile in close vessels without decomposition. It consists of 17 ammonia and 126 acid = 143 hydriodate of ammonia.—Gay-Lussac, *Ann. de Chim.*, xci.

Ammonia and Bromine act on each other with the evolution of nitrogen, and form hydrobromate of ammonia; but no bromide of nitrogen.

Bromate of Ammonia has not been examined.

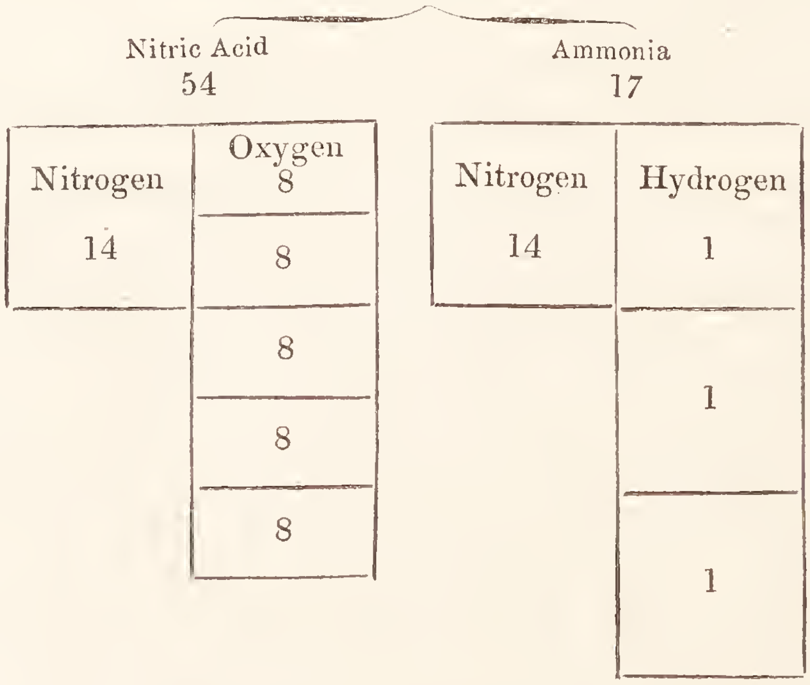
Hydrobromate of Ammonia is a volatile prismatic salt, becoming yellow and slightly acid by exposure to air. It is constituted of equal volumes of hydrobromic acid and ammonia.

Hydrofluate of Ammonia.—According to Berzelius, the neutral fluate is best obtained by heating in a platinum crucible a mixture of one part of muriate of ammonia with 2.25 parts of fluoride of sodium, both in fine powder: the cover of the crucible should be inverted, and contain water, to be replaced as it evaporates. A gentle heat sublimes the salt, which attaches itself in small prismatic crystals to the cool cover. If the salts were moist, ammonia is evolved, and an acid salt obtained. Fluate of ammonia is permanent in the air, readily soluble in water, and less so in alcohol. At a high temperature it melts and sublimes; it corrodes glass, and its solution furnishes a ready means of etching upon it: it absorbs ammonia, but does not retain it when sublimed. When its solution is evaporated, ammonia escapes, and a remarkably deliquescent *bifluate of ammonia*, imperfectly crystallizable, remains.

Nitrite of Ammonia is obtained when neutral nitrite of lead is decomposed by sulphate of ammonia. Its solution is decomposed by a very gentle heat, and evolves nitrogen; but it remains neutral. Exposed to spontaneous evaporation in a dry atmosphere, an irregularly crystallized mass is obtained, which melts, and is decomposed when heated, being resolved into nitrous oxide, water, and ammonia. (Berzelius.)

Ammonia and Nitric Acid—Nitrate of Ammonia.—This salt may be procured by the direct union of ammonia with nitric acid; or more easily, by saturating dilute nitric acid with carbonate of ammonia. It has been mentioned as the source of nitrous oxide, and when carefully heated it is entirely resolved into that gas and water. It consists, in the dry state, of one proportional of nitric acid = 54 + one proportional of ammonia = 17, and therefore the representative number of nitrate of ammonia is 71. Or it may be considered as containing two proportionals of nitrogen, three of hydrogen, and five of oxygen, as the following symbols show:—

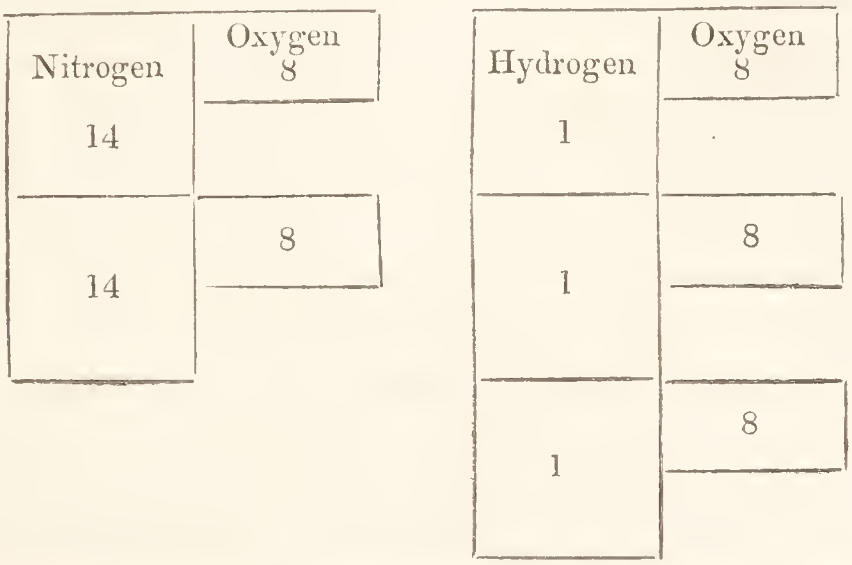
Nitrate of Ammonia.



Nitrous oxide consists of 1 proportional of nitrogen = 14 + 1 of oxygen = 8; hence the 2 proportionals of nitrogen in the salt (1 in the acid, and 1 in the ammonia) will require

2 of oxygen to produce nitrous oxide, and the remaining 3 of oxygen will unite to the 3 of hydrogen, and form water; and accordingly nitrous oxide and water are the only possible results; so that the elements, after the decomposition of the salt, are arranged thus:—

Two proportionals of Nitrous Oxide. Three proportionals of Water.



Nitrate of ammonia has long been known, and was formerly called *Nitrum flammans*, in consequence of its rapid decomposition with a slight explosion when heated to about 600°. It differs in form according to the manner in which its solution has been evaporated; if at a temperature below 100°, its crystals are six-sided prisms terminated by six-sided pyramids; if boiled down, its crystals are thin and fibrous; it is deliquescent, and soluble in twice its weight of water at 60°, and in its own weight at 212°. Its taste is acrid and bitter. It contains different proportions of water of crystallization; according to Berzelius, the prismatic variety affords 11.232 *per cent.*; hence it may be considered as containing

1 proportional of nitric acid . .	54. . .	67.625
1 ,, ammonia . .	17. .	21.143
1 ,, water . . .	9. . .	11.232
	80.	100.

(*Ann de Chim.*) According to Davy, the fibrous variety contains 8.2 *per cent.*; and the compact, obtained by evaporating the solution till it concretes, 5.7 *per cent.* of water of crystallization.—Davy's *Researches*, p. 71.

Atmospheric Air.—The composition of atmospheric air has been frequently alluded to in the preceding pages; and as the student is now acquainted with its essential component parts, namely, oxygen and nitrogen, it may be right to consider its properties more at length.

The atmosphere is a thin, transparent, invisible, and elastic fluid, which surrounds and revolves with our planet, and reaches to a considerable height above its surface, probably between 40 and 50 miles.

That air is a ponderous body was first suspected by Galileo, who found that a copper ball, in which the air had been condensed, weighed heavier than when the air was in its ordinary state of tension. The fact was afterwards demonstrated by Torricelli, whose attention was drawn to the subject by the attempt of a well-digger at Florence to raise water by a sucking-pump to a height exceeding 33 feet. It was then found that the pressure of the atmosphere, and not Nature's abhorrence of a vacuum, was the cause of the ascent of the water in the pump-pipe, and that a column of about the height mentioned was sufficient to equipoise the atmosphere, which, at the level of the sea, presses with a weight of about fifteen pounds on every square inch of surface, and is capable of supporting a column of water about 34 feet high, and one of mercury 30 inches.

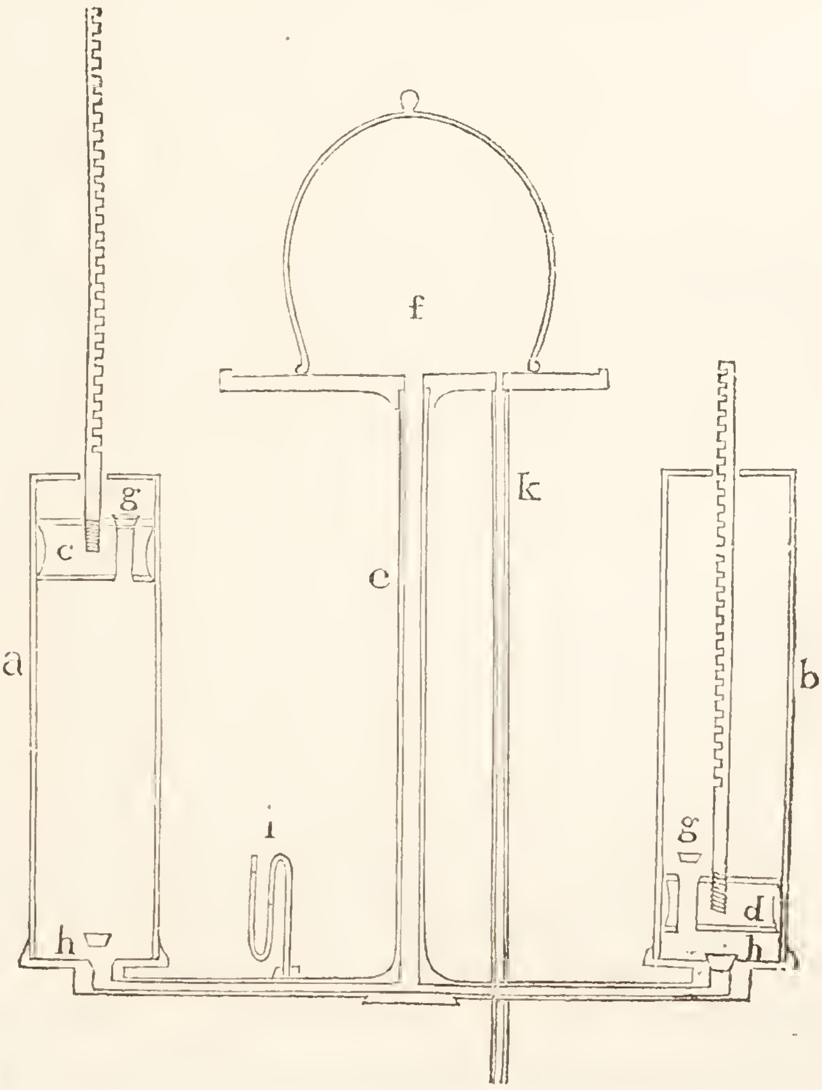
In 1643, Torricelli filled a glass tube, 3 feet long and closed at one end, with quicksilver, and inverted it in a basin of the same fluid; he found that the mercury fell about 6 inches, so that the atmosphere appeared capable of counterbalancing a column of mercury 30 inches in height. The empty space, in the upper part of the tube, has hence been called the *Torricellian vacuum*, and is nearly the most perfect that can be formed.

Paschal and Torricelli afterwards observed that, upon ascending a mountain, the quicksilver fell in the tube, because there was less air above to press upon the surface of the metal in the basin; and thus a method of measuring the heights of mountains by the *barometer*, as the instrument is now called, was devised. Sir Henry Englefield has constructed a barometer expressly for these investigations, the mode of using which is described in the *Journal of Science and the Arts*, vol. v. p. 229.

The barometer indicates, by its rise and fall, a corresponding change in the density of the atmosphere. At the surface of the earth the mean density or pressure is considered equal to the support of a column of quicksilver 30 inches high.

			Inches.
At 1000	feet above the surface	the column falls to	28.91
2000	"	"	27.86
3000	"	"	26.85
4000	"	"	25.87
5000	"	"	24.93
1 mile	"	"	24.67
2	"	"	20.29
3	"	"	16.68
4	"	"	13.72
5	"	"	11.28
10	"	"	4.24
15	"	"	1.60
20	"	"	0.95

The general mechanical properties of the air are best illustrated by the *air-pump*, the construction of which much resembles that of the common sucking-pump used for raising water, excepting that all the parts are more accurately and nicely made, the object being to exhaust the air as completely and expeditiously as possible. The annexed sketch will give



an idea of the operation of the common air-pump. *a b* are cylinders, into which the sliding-pistons *c d* are accurately fitted: *e* is a tube issuing from the bell-glass placed upon a brass plate *f*, and entering the lower part of the cylinders at *h h*, where are valves opening upwards. In each piston is also a valve opening upwards at *g g*. The cylinder *a* represents the piston in the act of being drawn up. By elevating the piston *c*, an attempt will be made to form a vacuum underneath it; but a portion of the air, in consequence of its elasticity, will pass out of the bell *f*, along the tube *e*, and elevating the valve *h*, will fill the space below the piston, the valve *g* being kept closed by the weight of the incumbent atmosphere. In the cylinder *b* the piston is represented in the act of depression, the valve *h* therefore is forced down upon the orifice, which it perfectly closes; and the air, confined between it and the piston, now makes its escape by the piston-valve *g*, which is accordingly open, so that at every stroke of the pump a portion of air is withdrawn from the receiver *f*.

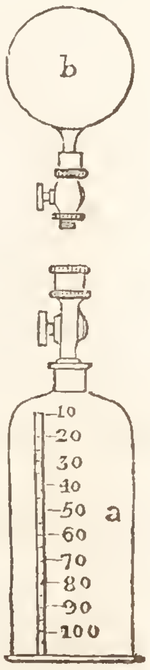
With this air-pump it is obviously impossible to obtain more than an imperfect vacuum in the receiver *f*, for the valves can only act by the elasticity of the remaining air; and, accordingly, if a barometer be placed under the receiver, the mercury will never attain a level in the tube and basin, but will always indicate a degree of pressure, as is shown by the small syphon gauge at *i*; and if a tube three feet long have its upper end opening into the receiver, and its lower end plunged into a basin of mercury, the mercury will never rise so high as in the common barometer, where the vacuum above it is more perfect, but will indicate the pressure of a remnant of air in the receiver. The syphon gauge, and the barometer as applied at *k*, are very useful appendages to the air-pump, as showing the degree of exhaustion, and its permanence.

The operation of the pump in removing air, and the mechanical properties of the atmosphere, may be shown by a variety of experiments. Its pressure is illustrated by the force with which the bell-glass is pressed down upon the plate of the pump; the absence of its buoyancy, by the descent of a guinea and a feather at the same time in the exhausted receiver; and by the preponderance of the larger of two bodies which balance each other in the open air. The want of resistance in the exhausted receiver is also shown by the equal duration of the motion of two fly-wheels, with their plates placed in different directions.

The extreme elasticity of the air, and the changes of bulk which it is constantly sustaining under variations of pressure and of temperature, have been already partially adverted to. The general law of its compression was originally developed by Boyle in 1662, and afterwards investigated by Mariotte. They found that the volume of air, and all other elastic fluids retaining that state, was inversely as the pressures acting upon them. Thus a volume of air = 100 under any given pressure, will be diminished to 50 when that pressure is doubled; and expanded to 200, when the pressure is diminished by one half. From the experiments of Oersted (*Edinburgh Journal of Science*, iv.), this law applies under very high pressures; indeed, till liquefaction is effected. We have, however, no evidence of the liquefaction of atmospheric air under any pressure, Mr. Perkins's experiments upon that subject (*Phil. Trans.*) not being in any way conclusive.

The specific gravity of atmospheric air, at mean temperature and pressure, that is, the thermometer being at 60°, and the barometer at 30 inches, is usually considered as = 1. It is about 828 times lighter than its bulk of water, and 11260 times lighter than its bulk of mercury, 100 cubical inches weighing 30.49 grains. Compared with hydrogen its specific gravity is as 14.4 to 1.

For ascertaining the specific gravity of gaseous bodies, a good air-pump is essentially requisite; a light glass balloon or flask *b*, and a graduated air-jar *a*, each supplied with stop-cocks, are also required.



Dr. Henry, in his *Elements of Chemistry*, and Mr. Faraday, in his *Chemical Manipulation*, have given explicit and extended directions for determining the specific gravities of gases, to which the reader is referred, and of which the following is an abstract.

The gases should be retained and collected over mercury, and carefully dried by exposing them to proper substances for absorbing the moisture which they hold in solution, and which would sometimes materially affect the accuracy of the result; or they should be taken saturated with moisture, and a correction afterwards made for the weight of the vapour contained in a given bulk of the gas.

Supposing the receiver *a* to be filled with any gas, the weight of which is to be ascertained, we screw the cock of the vessel *b* on the plate of an air-pump, and exhaust it as completely as possible. The weight of the exhausted vessel is then very accurately taken, even to a small fraction of a grain; and it is screwed upon the air-cock of the receiver *a*. On opening both cocks, the last of which should be turned very gradually, the gas ascends from the vessel *a;* and the quantity which enters into the flask is known by the graduated scale on *a*. On weighing the vessel a second time, we ascertain how many grains have been admitted. If we have operated on common air, we shall find its weight to be at the rate of 30.49 grains to 100 cubical inches. The same quantity of oxygen gas will weigh 33.88 grains, and of carbonic acid gas 46.59 grains.

In experiments of this kind it is necessary either to operate with the barometer at 30 inches, and the thermometer at 60° Fahrenheit, or to reduce the volume of gas employed to that pressure and temperature, by rules which are given in the note*. Great care is to be taken, also, not to warm any of

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* RULES FOR REDUCING THE VOLUME OF GASES TO A MEAN HEIGHT OF THE BAROMETER, AND MEAN TEMPERATURE.

i. *From the space occupied by any quantity of gas under an observed degree of pressure, to infer what its volume would be under the mean height of the barometer, taking this at* 30 *inches, as is now most usual.*

This is done by the rule of proportion; for, as the mean height is to the observed height, so is the observed volume to the volume required. For example, if we wish to know what space would be filled, under a pressure of 30 inches of mercury, by a quantity of gas, which fills 100 inches, when the barometer is at 29 inches—

$$30 : 29 :: 100 : 96.66.$$

The 100 inches would, therefore, be reduced to 96.66.

ii. *To estimate what would be the volume of a portion of gas, if brought to the temperature of* 60° *Fahrenheit.*

Divide the whole quantity of gas by 480; the quotient will the vessels by contact with the hands, from which they should be defended by a glove. On opening the communication between the receiver and the exhausted vessel, if any water be lodged in the air-cock attached to the former, it will be forcibly

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show the amount of its expansion or contraction by each degree of Fahrenheit's thermometer. Multiply this by the number of degrees which the gas exceeds or falls below 60°. If the temperature of the gas be above 60°, subtract, or if below 60°, add, the product to the absolute quantity of gas; and the remainder in the first case, or sum in the second, will be the answer. Thus, to find what space 100 cubic inches of gas at 50° would occupy if raised to 60°, divide 100 by 480; the quotient 0.208 multiplied by 10 gives 2.08, which added to 100 gives 102.08, the answer required. If the temperature had been 70°, and we had wished to know the volume which the gas would have occupied at 60°, the same number 2.08 must have been subtracted from 100, and 97.92 would have been the answer.

iii. In some cases, it is necessary to make a double correction, or *to bring the gas to a mean both of the barometer and thermometer.* We must then first correct the temperature, and afterwards the pressure. Thus, to know what space 100 inches of gas at 70° Fahrenheit, and 29 inches barometer, would fill at 60° Fahrenheit and 30 inches barometer, we first reduce the 100 inches, by the second process, to 97.92. Then by the first,

30 : 29 :: 97.92 : 94.63.

Or 100 inches, thus corrected, would be only 94.63.

iv. *To ascertain what would be the absolute weight of a given volume of gas at a mean temperature, from the known weight of an equal volume at any other temperature:* first, find by the second process what would be its bulk at a mean temperature; and then say, as the corrected bulk is to the actual weight, so is the observed bulk to the number required. Thus, if we have 100 cubic inches of gas weighing 50 grains at 50° Fahrenheit, if the temperature were raised to 60° they would expand to 102.08. And

102.08 : 50 :: 100 : 49.

Therefore 100 inches of the same gas at 60° would weigh 49 grains.

v. *To learn the absolute weight of a given volume of gas under a mean pressure, from its known weight under an observed pressure,* say, as the observed pressure is to the mean pressure, so is the driven into the latter, and the experiment will be frustrated. This may be avoided by using great care in filling the receiver with water, before passing into it the gas under examination.

The specific gravity of any gas compared with common air is readily known, when we have once determined its absolute weight. Thus, if 100 cubic inches of air weigh 30.49 grains, and the same quantity of oxygen gas weigh 33.88 grains, we say,

30.49 : 33.88 :: 1.000 : 1.111.

The specific gravity of oxygen gas, compared with atmospheric air, will therefore be as 1.111 to 1.000.

We may determine, also, the specific gravity of gases more simply by weighing the flask, first when full of common air, and again when exhausted; and afterwards by admitting into it as much of the gas under examination as it will receive, and weighing it a third time. Now as the loss between the first and second weighing is to the gain of weight on admitting the gas, so is common air to the gas whose specific gravity we are estimating. Supposing, for example, that by exhausting the flask it loses 30.49 grains, and that by admitting carbonic acid it gains 46.59; then

30.49 : 46.59 :: 1.000 : 1.527.

The specific gravity of carbonic acid is therefore 1.527, air being taken at 1.000. And knowing its specific gravity, we

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observed weight to the corrected weight. For example, having 100 inches of gas which weigh 50 grains under a pressure of 29 inches, to know what 100 inches of the same gas would weigh, the barometer being 30 inches.

29 : 30 :: 50 : 51.72.

Then 100 inches of the same gas, under 30 inches' pressure, would weigh 51.72 grains.

vi. In some cases it is necessary to combine the two last calculations. Thus, if 100 inches of gas at 50° Fahrenheit, and under 29 inches' pressure, weigh 50 grains, to find what would be the weight of 100 inches at 60° Fahrenheit, and under 30 inches of the barometer, first correct the temperature, which reduces the weight to 49 grains. Then,

29 : 30 :: 49 : 50.7.

100 inches, therefore, would weigh 50.7 grains.

can, without any further experiment, determine the weight of 100 cubic inches of carbonic acid; for, as the specific gravity of air is to that of carbonic acid, so is 30.49 to the number required; or

$$1.000 : 1.527 :: 30.49 : 46.59.$$

100 cubic inches, therefore, of carbonic acid will weigh 46.59 grains.

It has already been observed that gas, when standing over water, becomes saturated with aqueous vapour, the quantity being proportional to the temperature. In such cases a part of the observed volume, as well as of the weight, is due to vapour, which therefore must be determined before the actual weight of the gas can be accurately calculated. The following table (Faraday, *Manipulation*, p. 381) exhibits the proportion by volume of aqueous vapour existing in any gas standing in contact with water at the corresponding temperatures and at mean barometric pressure.

40°	.00933
41	.00973
42	.01013
43	.01053
44	.01093
45	.01133
46	.01173
47	.01213
48	.01253
49	.01293
50	.01333
51	.01380
52	.01426
53	.01480
54	.01533
55	.01586
56	.01640
57	.01693
58	.01753
59	.01810
60	.01866
61°	.01923
62	.01980
63	.02050
64	.02120
65	.02190
66	.02260
67	.02330
68	.02406
69	.02483
70	.02566
71	.02653
72	.02740
73	.02830
74	.02923
75	.03020
76	.03120
77	.03220
78	.03323
79	.03423
80	.03533

By reference to this table, which is founded upon the experiments of Mr. Dalton and Dr. Ure, and includes any temperature at which gases are likely to be weighed, the proportions in bulk of vapour present, and consequently of the dry gas, may easily be ascertained. For this purpose the observed temperature of the gas should be looked for, and opposite to it will be found the proportion in bulk of aqueous vapour at a pressure of 30 inches. The volume to which this amounts should be ascertained and corrected to mean temperature. Then the *whole* volume is to be corrected to mean temperature and pressure, and the corrected volume of vapour subtracted from it. This will leave the corrected volume of dry gas. It has been ascertained in a manner approaching to perfect accuracy, that a cubic inch of permanent aqueous vapour corrected to the temperature of 60°, and a mean pressure of 30 inches, weighs 0.1929 grains. The weight, therefore, of the known volume of aqueous vapour is now easily ascertained, and this being subtracted from the weight of the moist gas, will give the weight of the dry gas, the volume of which is also known.

When it is required to deprive gases of their mixed vapour, so as to render them *dry*, they may be slowly passed for the purpose through a tube about half an inch diameter, and from two to three feet long, containing fragments of fused and dry chloride of calcium, which, by its strong attraction for moisture, effects the desiccation of the gas. A few gases are, however, absorbed by it, in which case fused potassa, or fused carbonate of potassa, duly comminuted, may be substituted. Some gases are conveniently dried by exposing them to a surface of sulphuric acid. (See Faraday's *Manipulation*, p. 386.)

Assuming atmospheric air at 30 inches barometrical pressure, and 60° temperature = 1, the first column of the following table exhibits a series of comparative specific gravities; the second contains the weight of 100 cubic inches, calculated from the preceding column:—

GAS.	Specific Grav.	100 Cub. In.
Atmospheric air	1.0000	30.409
Oxygen	1.111	33.88
Chlorine	2.500	76.25
Oxide of Chlorine	2.360	72.012
Iodine (vapour of)	8.675	264.750
Hydrogen	0.0694	2.118
Water (vapour of)	0.625	19.062
Muriatic acid	1.284	39.183
Hydriodic acid	4.340	133.434
Nitrogen	0.972	29.652

GAS.	Specific Grav.	100 Cub. In.
Nitrous oxide	1.527	46.596
Nitric oxide	1.041	31.770
Nitrous acid	3.162	97.428
Ammonia	0.590	18.00
Sulphurous acid	2.222	67.777
Sulphuretted hydrogen	1.180	36.00
Phosphuretted hydrogen	0.902	27.537
Hydrophosphoric gas	0.972	29.652
Carbonic oxide	0.972	29.652
Chlorocarbonic acid	3.472	105.902
Carbonic acid	1.527	46.597
Carburetted hydrogen (olefiant)	0.972	29.652
Cyanogen	1.805	55.068
Chlorocyanic acid	2.152	65.658
Hydrocyanic acid	0.937	28·593
Sulphuret of carbon (vapour of)	2.637	80.484
Fluoboric gas	2.400	72.50
Fluosilicic gas	3.5740	110.78
Alcohol (vapour of)	1.600	48.714
Sulphuric ether (ditto)	2.570	78.36
Muriatic ether (ditto)	......	......
Hydriodic ether (ditto)	......	......
Chloric ether (ditto)	......	......
Oil of turpentine (ditto)	5.211	158.896

Atmospheric air has already been stated to consist essentially of oxygen and nitrogen; these gases are merely in a state of mechanical mixture, and by no means, as some have supposed, in chemical combination.

There are various ways of learning the proportion which the oxygen bears to the nitrogen; and as the relative fitness of the air for breathing has sometimes been considered as depending upon the quantity of oxygen contained in a given volume, the instruments used in these experiments have been called *eudiometers*.

From facts already stated, it is obvious, that if atmospheric air, mixed with a certain quantity of hydrogen, be detonated by the electric spark, the absorption will be proportionate to the quantity of oxygen present.

When 100 measures of pure hydrogen are mixed with 100 of pure oxygen, the diminution of bulk after detonation will amount to 150 parts, that is, one volume of oxygen requires for its saturation two of hydrogen. If we introduce into the graduated detonating tube 300 measures of common air, and

200 of pure hydrogen, there will remain, after detonation, 305 measures; so that 195 measures will have disappeared, of which one-third may be estimated as pure oxygen: hence 300 parts of air have thus lost 65 of oxygen, or about 21 *per cent.*

The general rule, therefore, for estimating the purity of air by hydrogen gas may be stated as follows:—Add to 3 measures of the air under examination 2 measures of pure hydrogen; detonate; and, when the vessel has cooled, observe the absorption; divide its amount by 3, and the quotient is the quantity of oxygen.

Upon the same principle, detonation of mixtures of oxygen and hydrogen is often resorted to, with a view of ascertaining the purity of those gases. Thus, suppose 100 measures of oxygen, and 300 of hydrogen, to be reduced by detonation to 130, the whole diminution will be = 270, which, divided by 3, gives 90 for the quantity of oxygen; so that it contained 10 *per cent.* of some gas, not condensible by detonation with hydrogen.

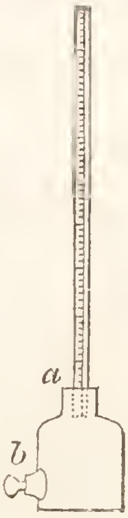
To ascertain the purity of hydrogen, it may be detonated with excess of pure oxygen. Thus, if we add 100 of pure oxygen to 100 of hydrogen, and detonate, there will be a diminution equal to two-thirds, or 150 parts, if the hydrogen be pure. If, however, we suppose 100 of pure oxygen, mixed with 100 of hydrogen, to produce, after detonation, a residue of 80 measures; the diminution will then have been only 120 measures, of which two-thirds, or 80 measures, are hydrogen: so that the inflammable gas will have contained 20 *per cent.* of some other gaseous body, not condensible by detonation with hydrogen.

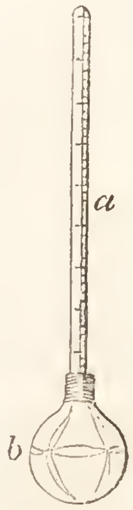
This mode of ascertaining the purity of atmospheric air was first resorted to by Volta, and it is susceptible of great accuracy, since hydrogen and oxygen are easily procured nearly pure. An improved detonating tube for these purposes has been described by M. Gay-Lussac, *Ann. de Chim. et Phys.* iv. 188.

The best form of instrument for detonating gaseous mixtures is that contrived by Dr. Ure; it consists of a glass syphon with legs nearly of equal length, open and slightly funnel-shaped at one extremity, and hermetically sealed and supplied with platinum detonating wires at the other. The sealed leg is graduated by introducing successively equal weights of mercury from a glass measure; 7 ounces and 66 grains troy occupy the space of a cubic inch, and 34.25 grains represent $\frac{1}{100}$ of that volume. To use this instrument it is filled with mercury, and inverted in the pneumatic trough; a convenient quantity of the gaseous mixture is introduced, and having applied a finger to the orifice, the tube is removed and inverted so as to transfer the gas to the sealed leg, where its quantity is very accurately measured; we then pour a portion of mercury from the open end of the tube, so as to leave a space of about two inches, and closing the aperture with the thumb, detonate by the electric spark: the included portion of air serves as a spring, and, on withdrawing the thumb, the change of bulk is read off, having previously added mercury, so as to bring it to a level in both legs of the syphon. Any liquid or solid that is required, may then be passed up into the closed end for the analysis of the residuary gas. (Ed. *Phil. Trans.* January, 1818.)

The singular action of spongy platinum, already adverted to (page 171), may be resorted to, to effect the union of oxygen with hydrogen in eudiometrical experiments.

Scheele, in his eudiometrical experiments, employed *sulphuret of potassa*, the solution of which rapidly absorbs oxygen, as may be shown by agitating it with some atmospheric air in a graduated glass tube. In this experiment the nitrogen remains unaltered.



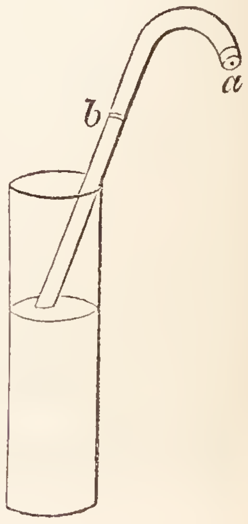


The best instruments for experiments by absorption are the eudiometric tubes of Dr. Hope (Nicholson's *Journal*, v. iv.) and Dr. Henry (*Elements*, vol. i. p. 149), as represented in the marginal woodcuts. The former consists of a small bottle, holding about three ounces, into which the graduated glass tube *a* is carefully fitted by grinding. It also has a ground stopper at *b*. To use it, the phial is filled with the solution of the alkaline sulphuret, and the tube *a*, containing the air to be examined, fitted into its place. After inverting and agitating the instrument, the stopper *b* may be opened under water, and the absorption is shown by the rise of the fluid in the tube. For the glass bottle Dr. Henry substituted the elastic gum bottle *b*, in the neck of which a short piece of glass tube is secured, into which the tube *a* is fitted by grinding.

In the *Philosophical Transactions* for 1807, Mr. Pepys has described a modification of this eudiometer, which may be often advantageouly employed in delicate experiments, and by which an absorption of only $\frac{1}{1000}$ part of the gas under examination may be measured.

When nitric oxide gas and atmospheric air are mixed, there is a production of nitrous acid, in consequence of the union of oxygen with the oxide; and if the mixture be made over water, an absorption proportional to the quantity of nitrous acid formed ensues. Upon this principle nitric oxide may be used in eudiometrical experiments; and, if proper precautions be attended to, it furnishes tolerably accurate results. Dr. Priestley and Mr. Cavendish (*Phil. Trans.* 1783) availed themselves of this mode, and Mr. Dalton has offered some remarks upon its relative accuracy (*Phil. Mag.* vol. xxviii.) The most certain results are obtained by adding to 100 parts of the atmospheric air, previously introduced into a small beer-glass, an equal volume of nitric oxide gas. The mixture may be gently agitated, and in two or three minutes carefully decanted into a graduated tube, when it will be found, provided the nitric oxide be pure, that 84 measures have disappeared; of which one-fourth, or 21 measures, are oxygen.

Sir H. Davy suggested the use of a solution of sulphate of iron, impregnated with nitric oxide gas, for the absorption of oxygen; it may be employed in the same way as the alkaline sulphuret.



If a stick of phosphorus be confined in a portion of atmospheric air, it will slowly absorb the oxygen present. The rapid combustion of the same substance may also be conveniently resorted to. For this purpose a small piece of phosphorus may be introduced into the bulb of the tube *a*, containing a given measure of the air to be examined, confined over mercury, which, to prevent loss by expansion, should be suffered to occupy about half the tube, or to stand at *b*. The phosphorus may then be inflamed in the tube; and when the combustion is over, and the tube cold, the residuary air may be transferred for measurement. These eudiometrical methods were used by Lavoisier, Berthollet, and Seguin (*Annales de Chimie*, tom. ix. and xxxiv.), and are both susceptible of accuracy; and a loss of volume, nearly = 21 per cent. of the atmospheric air, will invariably be found to have occurred.

By experiments thus conducted, it has been found that the composition of the atmosphere is extremely uniform in all parts of the world, and at all heights above its surface; and that it consists of,

	By Measure.	By Weight.
Oxygen	21	23
Nitrogen	79	77
	100	100

Though these are the essential component parts of atmospheric air, it contains other substances, which, however, may be regarded as adventitious, and the quantity of which is liable to vary: of these, carbonic acid and aqueous vapour are the most important and constant. The quantity of the former may usually be considered as amounting to less than about .01 per cent.

The presence of aqueous vapour in the atmosphere is shown in a variety of ways, but most easily by exposing to it certain deliquescent substances which liquefy and increase in weight, in consequence of its absorption; and as the gases in general, unless artificially dried, also contain vapour of water, it is necessary, in delicate experiments, and in ascertaining their specific gravity, to take this ingredient into the account, or to separate it by proper means, such as exposure to very deliquescent substances, among which fused chloride of calcium is especially useful, under the precautions already mentioned.

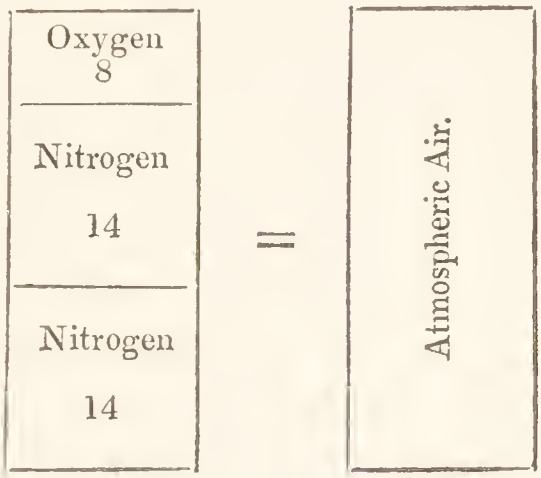
The quantity of water contained in air and gases is subject to variation. From the experiments of Saussure, Dalton, and Ure, already referred to, it appears that 100 cubic inches of atmospheric air at 57°, are capable of retaining 0.35 grains of watery vapour; in this state the air may be considered at its maximum of humidity; it would also appear that all the gases take up the same quantity of water when under similar circumstances, and that it consequently depends, not upon the density or composition, but upon the bulk of the gaseous fluid.

We are indebted to Mr. Dalton for some valuable information respecting the state in which water exists in air; from which it may be concluded that it is in the state of vapour, forming an independent atmosphere, mixed, but not combined with, or dissolved in, the air.

Hygroscopes and *hygrometers* are instruments which show the presence of water in the air, its variation in quantity, and its actual quantity existing in a given bulk of air at any given time. Saussure employs a human hair, which, by its dilatations and contractions in moisture and dryness, is made to turn an index; Deluc used a thin strip of whalebone in the same way; Wilson employs a rat's bladder, which is filled with mercury, and tied on to a large thermometer tube, and by its dilatation and contraction causes the mercury to fall and rise in the tube, and thus to indicate changes in the moisture of the air. Mr. Daniell has constructed an hygrometer, which shows the constituent temperature of the moisture in the atmosphere, by its precipitation upon a cold surface; comparing this with the temperature of the atmosphere, the difference furnishes a datum for calculating the quantity of vapour in a given quantity of air, and affords indications usefully applicable to predicting change of weather. A detailed account of this instrument, and of the observations made with it, is given by Mr. Daniell in the *Quarterly Journal of Science*, vols. viii., ix. and x. Upon the whole, the ordinary constituents of the atmosphere may be considered as follows:

	By Measure.	By Weight.
Nitrogen	77.5	75.55
Oxygen	21.	23.32
Aqueous vapour	1.42	1.03
Carbonic acid	0.08	0.10
	100	100

If the relative bulk of oxygen to nitrogen be considered as 1 to 4, and many analysts will not allow that the atmosphere contains more than 20 of oxygen to 80 of nitrogen, it follows that it consists of one volume of oxygen to four of nitrogen, or, in reference to the atomic theory, of one proportional of oxygen = 8, and two of nitrogen = 14 × 2 = 28; which may be thus represented :—



It has already been remarked, that in all common cases of combustion in atmospheric air, the oxygen is absorbed, and enters into new combinations, whilst the nitrogen remains passive. In the same way in the function of respiration, a portion of the oxygen is converted into carbonic acid, and is expired along with the unaltered nitrogen. This constant consumption of oxygen has induced theorists to seek for some method of its restitution in a pure state to the atmosphere; and Dr. Priestley suggested the functions of the vegetable creation as at least one source of such renovation. But it appears from the calculations of De Saussure, that in these inquiries the enormous bulk or quantity of the atmosphere has been forgotten, and that the united effect of the different deteriorating processes would not occasion any sensible difference in the chemical composition of the whole mass for many hundred years. In these speculations it must always be remembered that the different parts of the atmosphere are constantly kept in a uniform state of mixture, by the propensity which gaseous bodies have, notwithstanding material differences in their specific gravities, to diffuse themselves equably through each other, and that this equality of mixture is further promoted by the constant agitation to which the air is subjected by winds, and by the varied temperature of different portions of the earth's surface.

The combustion of substances in the air under ordinary circumstances will be explained, by reference to the details given in the chapter on Oxygen. Some peculiar cases of combustion, however, which require more extended notice, have been ingeniously investigated by Sir H. Davy (*Essay on Flame*, and *Phil. Trans.*, 1817). In examining the effect of rarefaction upon combustion, he found that when hydrogen gas was inflamed at a fine orifice, so as to make a jet of flame of about one-sixth of an inch in height, and introduced under the receiver of an air-pump containing from 200 to 300 cubical inches of air, the flame enlarged as the receiver became exhausted; and when the gage indicated a pressure between four and five times less than that of the atmosphere, was at its maximum of size; it then gradually diminished below, but burned above, till the pressure was between seven and eight times less, when it became extinguished.

To ascertain whether the effect depended upon the deficiency of oxygen, he used a larger jet with the same apparatus, when the flame burned longer, and this when the atmosphere was rarefied ten times. When the larger jet was used, the point of the glass tube became white-hot, and continued red-hot till the flame was extinguished. It therefore occurred to him, that the heat communicated to the gas by this tube, was the cause that the combustion continued longer in the last trials when the larger flame was used; and the following experiments confirmed the conclusion. A piece of wire of platinum was coiled round the top of the tube, so as to reach into and above the flame. The jet of gas of one-sixth of an inch in height was lighted and the exhaustion made; the wire of platinum soon became white-hot in the centre of the flame, and a small point of wire near the top fused; it continued white-hot till the pressure was six times less; when it was ten times it continued red-hot at the upper part, and as long as it was dull red, the gas, though extinguished below, continued to burn in contact with the hot wire, and the combustion did not cease until the pressure was reduced thirteen times.

It appears from this result, that the flame of hydrogen is extinguished in rarefied atmospheres, only when the heat it produces is insufficient to keep up the combustion, which appears to be when it is incapable of communicating visible ignition to metal, and as this is the temperature required for the inflammation of hydrogen at common pressures, it appears that its *combustibility* is neither diminished nor increased by rarefaction from the removal of pressure.

According to this view with respect to hydrogen, it should follow that, amongst other combustible bodies, those which require least heat for their combustion ought to burn in more rarefied air than those that require more heat, and those that produce much heat in their combustion ought to burn, other circumstances being the same, in more rarefied air than those that produce little heat; and Sir Humphry's experiments confirm these conclusions. Thus olefiant gas, which approaches nearly to hydrogen in the heat produced by its combustion, and which does not require a much higher temperature for its inflammation, when its flame was made by a jet of gas from a bladder connected with a small tube furnished with a wire of platinum, under the same circumstances as hydrogen, ceased to burn when the pressure was diminished between ten and eleven times; and the flames of alcohol and of the wax taper, which require a greater consumption of heat for the volatilization and decomposition of their combustible matter, were extinguished when the pressure was five or six times less without the wire of platinum, and seven or eight times less when the wire was kept in the flame. Light carburetted hydrogen, which produces less heat in combustion than any of the common combustible gases, except carbonic oxide, and which requires a higher temperature for its inflammation than any other, had its flame extinguished, even though the tube was furnished with the wire when the pressure was below one-fourth.

The flame of carbonic oxide, which, though it produces little heat in combustion, is as inflammable as hydrogen, burned when the wire was used, the pressure being one-sixth.

The flame of sulphuretted hydrogen, the heat of which is in some measure carried off by the sulphur produced by its decomposition during its combustion in rare air, when burned in the same apparatus as the olefiant and other gases, was extinguished when the pressure was one-seventh.

Sulphur, which requires a lower temperature for its combustion than any common inflammable substance, except phosphorus, burned with a very feeble blue flame in air rarefied fifteen times, and at this pressure the flame heated a wire of platinum to dull redness, nor was it extinguished till the pressure was reduced to one-twentieth *.

Phosphorus, as has been shown by M. Van Marum, burns in an atmosphere rarefied sixty times; and Sir Humphry found that phosphuretted hydrogen produced a flash of light when admitted into the best vacuum that could be made by an excellent pump of Nairn's construction.

The mixture of chlorine and hydrogen inflames at a much lower temperature than that of hydrogen and oxygen, and produces a considerable degree of heat in combustion: it was therefore probable that it would bear a greater degree of rarefaction, without having its power of exploding destroyed; and this was found by many trials to be actually the case, contrary to the assertion of M. de Grotthus. Oxygen and hydrogen, in the proportion to form water, will not explode by the electrical spark when rarefied eighteen times; but hydrogen and chlorine, in the proportion to form muriatic acid gas, gave a distinct flash of light under the same circumstances, and they combined with visible inflammation when the spark was passed through them, the exhaustion being to one-twenty-fourth.

The experiment on the flame of hydrogen with the wire of platinum, and which holds good with the flames of the other gases, shows, that by preserving heat in rarefied air, or giving heat to a mixture, inflammation may be continued, when, under common circumstances, it would be extinguished. This was found to be the case in other instances, when the heat was differently communicated: thus, when camphor was burned in a glass tube, so as to make the upper part of the tube red hot, the inflammation continued when the rarefaction was nine times, whereas it would only continue in air rarefied six times, when it was burned in a thick metallic tube which could not be considerably heated by it. (Davy *on Flame*, p. 56.)

The influence of the admixture of other gases with atmos-

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* The temperature of the atmosphere diminishes in a certain ratio with its height, which must be attended to in the conclusions respecting combustion in the upper regions of the atmosphere, and the elevation must be somewhat lower than in arithmetical progression, the pressure decreasing in geometrical progression. There is, however, every reason to believe that the taper would be extinguished at a height of between 9 and 10 miles, hydrogen between 12 and 13, and sulphur between 15 and 16.

pheric air upon its power of supporting combustion, is another subject which has been elucidated by Sir H. Davy's experiments. He found that a wax taper was instantly extinguished in air mixed with one-tenth of silicated fluoric acid gas, and in air mixed with one-sixth of muriatic acid gas; but the flame of hydrogen burned readily in those mixtures, and in mixtures in which the flame of hydrogen was extinguished, the flame of sulphur burned.

The following simple experiment demonstrates this general principle. Into a long bottle with a narrow neck introduce a lighted taper, and let it burn till it is extinguished; carefully stop the bottle, and introduce another lighted taper, it will be extinguished before it reaches the bottom of the neck; then introduce a small tube containing zinc and diluted sulphuric acid, and at the aperture of which the hydrogen is inflamed; the hydrogen will be found to burn in whatever part of the bottle the tube is placed: after the hydrogen is extinguished, introduce lighted sulphur; this will burn for some time, and after its extinction, phosphorus will be as luminous as in the air, and, if heated in the bottle, will produce a pale yellow flame of considerable density.

In cases when the heat required for chemical union is very small, as in the instance of hydrogen and chlorine, a mixture which prevents inflammation will not prevent combination, *i. e.* the gases will combine without any flash. Thus, in mixing two volumes of carburetted hydrogen with one of chlorine and hydrogen, muriatic acid was formed throughout the mixture, and heat produced, as was evident from the expansion when the spark passed, and the rapid contraction afterwards, but the heat was so quickly carried off by the quantity of carburetted hydrogen that no flash was visible.

Steam, and such vapours as require considerable heat for their formation, have a less power of preventing combustion than permanent gases. Sir H. Davy found that a very large quantity of steam was necessary to prevent sulphur from burning. Oxygen and hydrogen exploded by the electric spark when mixed with five times their volume of steam; and even a mixture of air and carburetted hydrogen gas, the least explosive of all mixtures, required a third of steam to prevent its explosion, whereas one-fifth of nitrogen produced the effect. (Davy *on Flame*, p. 87.)

In the course of the above experiments, Sir Humphry endeavoured to ascertain what would be the effect of condensation on flame in atmospheric air, and whether the cooling power of the nitrogen would increase in a lower ratio, as might be expected, than the heat produced by the increase of the quantity of matter entering into combustion. He found considerable difficulties in making the experiments with precision; but he ascertained that both the light and heat of the flames of the taper, of sulphur and hydrogen, were increased by acting on them by air condensed four times; but not more than they would have been by an addition of one-fifth of oxygen.

He condensed air nearly five times, and ignited iron wire to whiteness in it by the Voltaic apparatus, but the combustion took place with very little more brightness than in the common atmosphere, and would not continue as in oxygen, nor did charcoal burn much more brightly in this compressed air than in common air. These experiments show that, (for certain limits at least) as rarefaction does not diminish considerably the heat of flame in atmospherical air, so neither does condensation considerably increase it; a circumstance of great importance in the constitution of our atmosphere, which at all the heights or depths at which man can exist, still preserves the same relations to combustion.

Section III. SULPHUR.

SULPHUR, or brimstone, is a brittle substance, of a pale yellow colour, somewhat translucent, insipid, and inodorous, but exhaling a peculiar smell when heated. Its specific gravity is 1.990. It becomes negatively electrical by heat and by friction, and is a non-conductor of electricity.

Sulphur is principally a mineral product, and occurs crystallized, its primitive form being a very acute octoëdron with an oblique base. These crystals are in a high degree doubly refractive. According to Mitscherlich, it has, when artificially crystallized, a different primitive form, namely, an oblique rhomboic prism.

When sulphur is heated to about 180°, it volatilizes, and its peculiar odour is strong and disagreeable; at about 200° it begins to fuse, and at 225° it is perfectly liquid; between 350° and 400° it becomes viscid, and of a deep brown colour, but regains its fluidity when cooled; and at about 600° it quickly sublimes in the form of an orange-coloured vapour, and may be collected either in a solid or pulverulent state, according to the rapidity of the process and the size of the condensing vessels. (*Thenard*, i. 197.) The residue is the *sulphur vivum* of old pharmacy. When sulphur, which has been heated to about 300°, is poured into warm water, it acquires the consistency of soft wax, and hardens on cooling. In this state it is sometimes used to take impressions of engraved stones; it is of a reddish colour, and of the specific gravity 2.3. When slowly cooled after fusion, it forms a fibrous crystalline mass. But Mr. Faraday has remarked that sulphur sometimes retains its fluidity, and does not concrete till touched by some solid body. This state appears somewhat analogous to that of water cooled in a quiescent state below its freezing point. (*Quarterly Journal*, xxi. 392.) It suffers no change by exposure to air, and is insoluble in water. It is met with in masses, in rolls or sticks, and in the form of powder, when it is usually called *flowers of sulphur*, or *sublimed sulphur*.

Sublimed sulphur, when examined by a microscope, appears composed of minute crystals; it is always slightly sour, and hence, for some pharmaceutical purposes, is directed to be washed with hot water.

Massive sulphur is chiefly brought to this country from Sicily; it occurs native, and is found associated with sulphate of lime, sulphate of strontia, and carbonate of lime. Its colour is various shades of yellow, and the transparent crystals are doubly refractive. Sulphur is not uncommon among volcanic products.

Roll-sulphur is chiefly obtained from sulphuret of copper in this country, and elsewhere abundantly from sulphuret of iron, or common pyrites; which is roasted, and the fumes received into a long chamber of brick-work, where the sulphur is gradually deposited; it is then purified by fusion, and cast into sticks. In this state, if grasped by the warm hand, it splits with a crackling noise.

For some pharmaceutical purposes sulphur is precipitated from its alkaline solutions, as from sulphuret of potassa, by an acid, and, when washed and dried, is in the form of a yellowish-grey impalpable powder; it is the *milk of sulphur* and *precipitated sulphur* of the *Pharmacopœiæ*. Dr. Thomson considers it as a compound of sulphur and water.—*System of Chem.* vol. i. 285.

The purity of sulphur may be judged of by heating it gradually upon a piece of platinum leaf; if free from earthy impurities, it should totally evaporate. It should also be perfectly soluble in boiling oil of turpentine.—Aikin's *Dictionary*, Art. SULPHUR.

It dissolves with some difficulty in alcohol: to effect this solution both substances should be brought together in the state of vapour; in the same way it may be dissolved in sulphuric ether.

When heated in the atmosphere to a little above 300°, it inflames and burns with a peculiar blue light; at a higher temperature its vapour kindles with a purple flame; and in oxygen it burns vividly, with a large lilac-coloured flame.

Sulphur forms four compounds with oxygen, all of which are possessed of acid properties; they are composed as follows:

	Sulphur.		Oxygen.		S.		O.
1. Hyposulphurous acid	16	+	8	=	1	+	1
2. Sulphurous acid .	16	+	16	=	1	+	2
3. Hyposulphuric acid	32	+	40	=	2	+	5
4. Sulphuric acid . .	16	+	24	=	1	+	3

It will be most convenient to describe these acids, not in the above order, but first to notice the sulphurous and the sulphuric, and afterwards the hyposulphurous and the hyposulphuric.

Sulphurous acid is a gaseous body, which may be obtained by several processes. It may be procured directly, by burning sulphur in oxygen gas; or indirectly, by boiling two parts of mercury in three of sulphuric acid; or by heating, in a small glass retort, a mixture of equal parts of black oxide of manganese and sulphur. It must be collected and preserved over mercury; for water takes up rather more than thirty times its bulk of this gas. This aqueous solution, when recently prepared, has a sulphurous, astringent taste, and destroys many vegetable colours; but, by keeping, it acquires a sour flavour, and reddens the generality of vegetable blues. Upon some colouring matters, as that of cochineal, it has scarcely any action; and when it does destroy colour, the original tint may often be restored by a stronger acid. A red rose, for instance, is bleached by dipping into a solution of sulphurous acid; but the colour is restored by immersion in dilute sulphuric acid. According to Grotthus, the sulphurous acid and certain colouring matters combine into colourless compounds, which are decomposed by more powerful acids.

Sulphurous acid escapes when its aqueous solution is boiled, but not when it is frozen. Its specific gravity at 60° is 1.05. Alcohol dissolves sulphurous acid more copiously than water; one volume taking up more than 100 of the gas. Monge and Clouet found, that at the freezing point, and under pressure, sulphurous acid assumed a liquid form; and the experiments of Mr. Faraday place the pressure required for this purpose at two atmospheres. M. Bussy (*Ann. of Phil.*, viii. 307. N. S.) has shown that this acid may be obtained in the liquid form at common atmospheric pressure, by passing it through tubes surrounded by a freezing mixture of salt and snow*. Its specific gravity is about 1.45, and it boils at 14°. In this state it evaporates with such rapidity at common temperatures as to generate a great degree of cold; by its aid mercury may easily be frozen, and it produces cold enough to liquefy chlorine, ammonia, and cyanogen.

If sulphur be burned in pure and perfectly dry oxygen, sulphurous acid is produced without any change in the volume of the gas, so that its composition is learned by the increase of weight; and as 100 cubic inches of oxygen (weighing 33.8 grains) dissolve 33.8 grains of sulphur, it is obvious that the sulphurous acid is composed of equal weights of sulphur and oxygen; and if we regard it as consisting of two proportionals of oxygen and one of sulphur, the latter element will be represented by the number 16; and the sulphurous acid, consisting of 1 proportional of sulphur = 16, and 2 of oxygen = 16, will be represented by 32, which is also its relative specific gravity to hydrogen, considering the latter as = 1; 100

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* See Faraday's Manipulation, p. 215.

cubical inches of sulphurous acid gas weigh 67.7 grains, and its specific gravity, compared with atmospheric air, is 2.222. This gas has a suffocating, nauseous odour, and an astringent taste; it extinguishes the flame of a taper, and kills animals.

Sulphurous acid suffers no change at a red heat, but if mixed with hydrogen, and passed through a red-hot tube, water is formed and sulphur deposited; under the same circumstances, it is also decomposed by charcoal, by potassium, and sodium, and probably by several other metals. It undergoes no change when mixed with oxygen, unless humidity or water be present, in which case a portion of sulphuric acid is formed. When mixed with chlorine, and in contact with water, sulphurous acid gives rise to sulphuric and muriatic acid, but the perfectly dry gases have no mutual action. Peroxide of lead, or of manganese, added to the aqueous solution of sulphurous acid, quickly convert it into sulphuric acid, and destroy its odour. Prepared by the combustion of sulphur, it is much used for bleaching cotton goods (*Quarterly Journal of Science*, iv. 196), and also for whitening silk and wool; in wine countries it is sometimes used to check vinous fermentation.

When sulphurous acid is mixed in equal volume with ammonia, a yellowish salt is produced, which is a *sulphite of ammonia*, and which consists of 32 sulphurous acid + 17 ammonia = 49. When formed by saturating liquid ammonia with sulphurous acid, it crystallizes in four and six-sided prisms, soluble in their own weight of water, and having an acrid taste. It is deliquescent, and becomes a *sulphate* by exposure to air. Sulphurous acid is expelled from its combinations by nearly all the other acids.

Sulphuric Acid.—This body was formerly obtained by the distillation of green vitriol, and called *oil of vitriol.* It is now procured in this country by burning a mixture of about 8 parts of sulphur and 1 of nitre in close leaden chambers containing water, by which the fumes produced are absorbed, and by evaporation the acid is procured in a more concentrated state. This improved method of preparing sulphuric acid was invented by Dr. Roebuck, about the year 1746.—Parkes's *Chemical Essays*, vol. ii.—*Prefatory History of Chemistry.*

Sulphuric acid, as usually met with, is a limpid, colourless fluid, having a specific gravity of 1.80 to 1.84; it boils at 620°, and freezes at 15°, contracting at the same time considerably in its dimensions. But the temperature at which the diluted acid congeals is singularly modified by the quantity of water which it contains. At the specific gravity of 1.78, it freezes at about 40°; but if the density be either increased or diminished, a greater cold is required for its congelation.—(Keir, *Irish Phil. Trans.*, iv. 88.) Its boiling point diminishes with its dilution; acid of the specific gravity of 1.78, boils at 435°, and acid of the specific gravity of 1.650 boils at 350°. —Dalton's *Chem. Phil.*, ii. 404.

In illustration of the fixedness of sulphuric acid, M. Bellani placed a leaf of zinc in the upper part of a closed bottle, the bottom of which was covered with the concentrated acid. The zinc retained its clean surface at the end of two years. (*Giornale di Fisica*, v. 197.)

It is acrid and caustic, and, when diluted with water, produces a very sour liquid. It rapidly absorbs water from the atmosphere, so that in moist weather three parts by weight increase to four in twenty-four hours. By exposure for a year, 1 oz. of acid acquired an increase of 6.25. Upon sudden mixture of sulphuric acid with water, condensation ensues, and much heat is evolved. Four parts of acid and one of water produce, when suddenly mixed, a temperature = 300°. According to Dr. Ure, the greatest heat is evolved by mixing 73 of acid with 27 of water. Even a boiling temperature, when it is concentrated, does not prevent its taking up moisture from the air; hence it cannot be concentrated so well in an open as in a close vessel, on which account retorts of glass or platinum are used for the last stage of its concentration by the manufacturers.

It chars animal and vegetable substances, and is apt to acquire a brown tinge from any small particles of straw, resin, or other matters that may accidentally have fallen into it.

In sulphuric acid 1 proportional of sulphur = 16, is combined with 3 of oxygen = 24, and, consequently, *dry* sulphuric acid is correctly represented by 16 + 24 = 40. In its ordinary state it contains water, and may therefore be called *hydrated sulphuric Acid.* It has been found by experiment, that 100 parts of sulphuric acid, specific gravity 1.85, contain 18.5 of water; consequently, it may be looked upon as composed of 1 sulphur + 3 oxygen + 1 water:

Or of Sulphur,	16.
Oxygen,	24.
Water	9.
	49. = number for liquid sulphuric acid.

100 parts of liquid sulphuric acid, of the specific gravity of 1.3530, contains 37.5 parts of dry sulphuric acid; or 46 of liquid acid, of the specific gravity 1.85.

The strength of sulphuric acid is best judged of by its saturating power, and by its specific gravity. Mr. Dalton (*New System of Chemical Philosophy*, vol. ii. p. 404) has published a Table, exhibiting the specific gravity and boiling point of the acid of various strengths. Dr. Ure has also given several valuable tables relating to this subject, in his *Experiments to determine the Law of Progression followed in the Density of Sulphuric Acid at different Degrees of Dilution* (*Quarterly Journal of Science and the Arts*, vol. iv. p. 114.) See, also, *Ure's Dictionary*, Art. ACID (SULPHURIC.) An extremely useful table of this kind will also be found in Mr. Parkes's *Essays* above quoted (vol. ii. p. 444.)

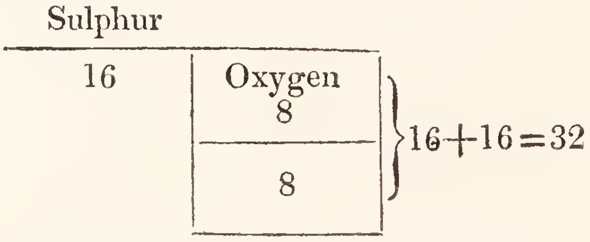
The following is Dr. Ure's Table:—

Liquid.	Sp. Gr.	Dry.	Liq.	Sp. Gr.	Dry.	Liq.	Sp. Gr.	Dry.
100	1.8485	81.54	66	1.5503	53.82	32	1.2334	26.09
99	1.8475	80.72	65	1.5390	53.00	31	1.2260	25.28
98	1.8460	79.90	64	1.5280	52.18	30	1.2184	24.46
97	1.8439	79.09	63	1.5170	51.37	29	1.2108	23.65
96	1.8410	78.28	62	1.5066	50.55	28	1.2032	22.83
95	1.8376	77.46	61	1.4960	49.74	27	1.1956	22.01
94	1.8336	76.65	60	1.4860	48.92	26	1.1876	21.20
93	1.8290	75.83	59	1.4760	48.11	25	1.1792	20.38
92	1.8233	75.02	58	1.4660	47.29	24	1.1706	19.57
91	1.8179	74.20	57	1.4560	46.48	23	1.1626	18.75
90	1.8115	73.39	56	1.4460	45.66	22	1.1549	17.94
89	1.8043	72.57	55	1.4360	44.85	21	1.1480	17.12
88	1.7962	71.75	54	1.4265	44.03	20	1.1410	16.31
87	1.7870	70.94	53	1.4170	43.22	19	1.1330	15.49
86	1.7774	70.12	52	1.4073	42.40	18	1.1246	14.68
85	1.7673	69.31	51	1.3977	41.58	17	1.1165	13.86
84	1.7570	68.49	50	1.3884	40.77	16	1.1090	13.05
83	1.7465	67.68	49	1.3788	39.95	15	1.1019	12.23
82	1.7360	66.86	48	1.3697	39.14	14	1.0953	11.41
81	1.7245	66.05	47	1.3612	38.32	13	1.0887	10.60
80	1.7100	65.23	46	1.3530	37.51	12	1.0809	9.78
79	1.6993	64.42	45	1.3440	36.69	11	1.0743	8.97
78	1.6870	63.60	44	1.3345	35.88	10	1.0682	8.15
77	1.6750	62.78	43	1.3255	35.06	9	1.0614	7.34
76	1.6630	61.97	42	1.3165	34.25	8	1.0544	6.52
75	1.6520	61.15	41	1.3080	33.43	7	1.0477	5.71
74	1.6415	60.34	40	1.2999	32.61	6	1.0405	4.89
73	1.6321	59.52	39	1.2913	31.80	5	1.0336	4.08
72	1.6204	58.71	38	1.2826	30.98	4	1.0268	3.26
71	1.6090	57.89	37	1.2740	30.17	3	1.0206	2.446
70	1.5975	57.08	36	1.2654	29.35	2	1.0140	1.63
69	1.5868	56.26	35	1.2572	28.54	1	1.0074	0.8154
68	1.5760	55.45	34	1.2490	27.72			
67	1.5648	54.63	33	1.2409	26.91			

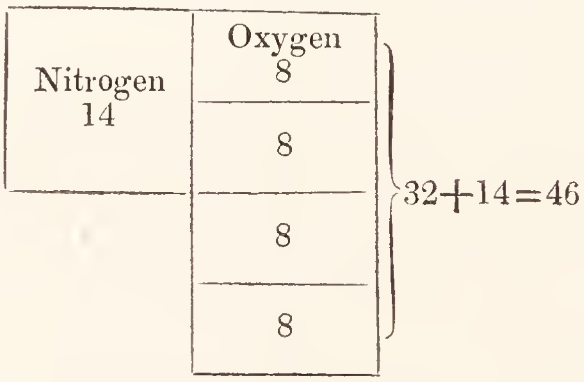
The *formation* of sulphuric acid by the combustion of sulphur and nitre is as follows:—

The sulphur, by burning in contact with atmospheric air, forms *sulphurous acid.* The nitre gives rise to the production of *nitric oxide,* which, with the oxygen of the air, produces *nitrous acid gas.* When these gases (*i. e.,* sulphurous and nitrous acids) are *perfectly dry,* they do not act upon each other, but moisture being present in small quantity, they form a white solid, which is instantly decomposed when put into water; the nitrous acid reverts to the state of nitric oxide, having transferred one additional proportional of oxygen to the sulphurous acid, and, with water, producing the sulphuric acid; while the nitric oxide, by the action of the air, again affords nitrous acid, which plays the same part as before.

Sulphurous acid consists of

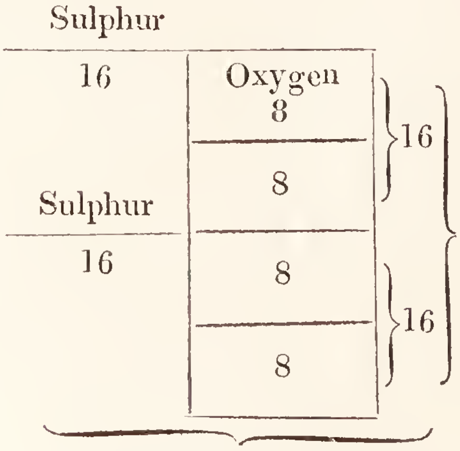


And nitrous acid contains

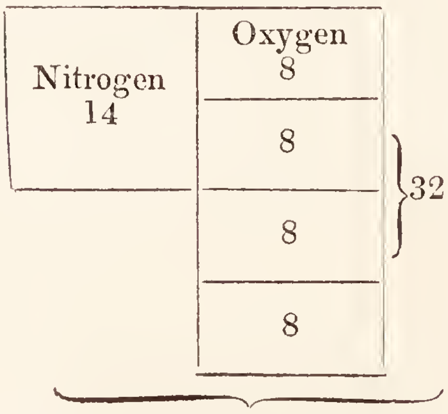


Hence every *two* portions of sulphurous acid require *one* of nitrous acid, which transfers *two* of oxygen, and passes back into the state of nitric oxide, sulphuric acid being, at the same time, produced.

The gases, therefore, before decomposition, may be thus represented:—

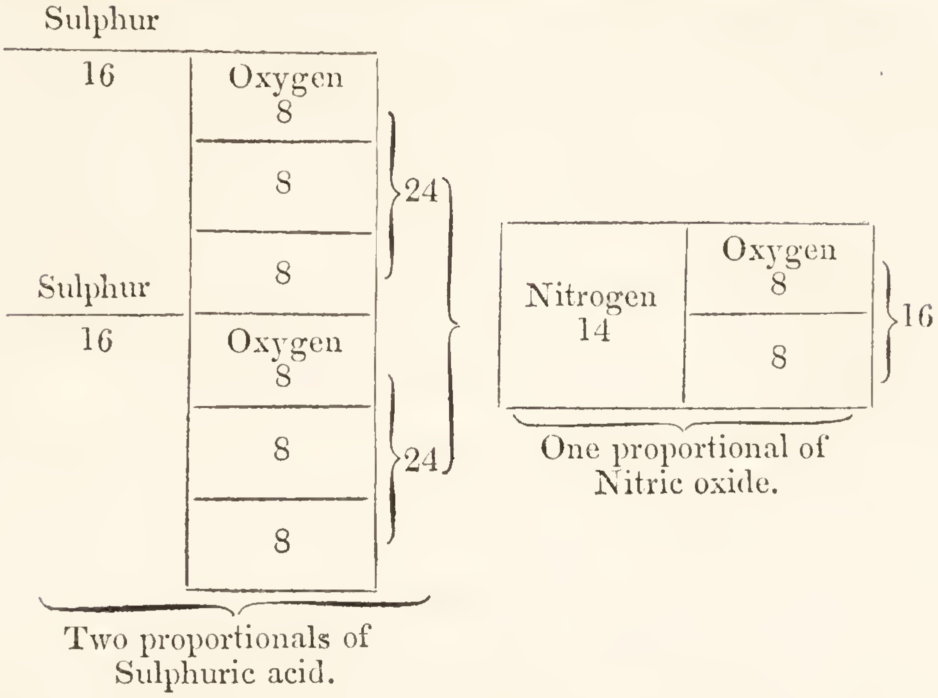


Two proportionals of
Sulphurous acid.



One proportional of
Nitrous acid gas.

And after decomposition as follows:—



When liquid hyponitrous acid, obtained by the distillation of nitrate of lead, is mixed with sulphuric acid, a crystallized compound of the two acids is formed, provided the temperature be not too high, which, when put into water, evolves nitric oxide gas, and is, according to Gay-Lussac, analogous to the above-mentioned substance produced by mixing humid sulphurous and nitrous acid gases (*Ann. de Chim. et Phys.* i. 408).

The decomposition of sulphuric acid may be effected by passing it through a red-hot platinum tube, when it is resolved into sulphurous acid, oxygen, and water.

When heated with charcoal, sulphuric acid gives rise to the production of carbonic and sulphurous acids; with phosphorus it produces phosphoric and sulphurous acids; and, with sulphur, sulphurous acid is the only product. It is decomposed by several of the metals, which become oxidized, and evolve sulphurous acid, as shown in the production of this acid, by boiling sulphuric acid with mercury, tin, lead, &c.

Sulphuric acid is largely consumed in a variety of manufactures. It is used by the makers of nitric, muriatic, citric, and tartaric acids; by bleachers, dyers, tin-plate makers, brass-founders and gilders. For these purposes it is generally sufficiently pure as it comes from the wholesale manufacturer; but, as traces of lead, lime, iron, and potassa are often found in it, it often requires to be purified by distillation for the use of the experimental chemist.

The distillation of this acid in glass retorts requires some precaution, in consequence of the violent jerks which the production of its vapour occasions, and which often break the vessel; this may be prevented by putting some strips of platinum into the acid; it then boils quietly, and it is only necessary to take care that the neck of the retort and receiver are not broken in consequence of the high temperature of the condensing acid. This very useful contrivance to the practical chemist was first shown me by Mr. James South.

Dr. Ure has the following remarks on the distillation of this acid:—" I take a plain glass retort, capable of holding from two to four quarts of water, and put into it about a pint measure of the sulphuric acid, (and a few fragments of glass,) connecting the retort with a large globular receiver, by means of a glass tube four feet long, and from one to two inches in diameter. The tube fits very loosely at both ends. The retort is placed over a charcoal fire, and the flame is made to play gently on its bottom. When the acid begins to boil smartly, sudden explosions of dense vapour rush forth from time to time, which would infallibly break small vessels. Here, however, these expansions are safely permitted, by the large capacity of the retort and receiver, as well as by the easy communication with the air at both ends of the adopter tube. Should the retort, indeed, be exposed to a great intensity of flame, the vapour will no doubt be generated with incoercible rapidity, and break the apparatus. But this accident can proceed only from gross imprudence. It resembles, in suddenness, the explosion of gunpowder, and illustrates admirably Dr. Black's observation, that, but for the great latent heat of steam, a mass of water, powerfully heated, would explode on reaching the boiling temperature. I have ascertained, that the specific caloric of the vapour of sulphuric acid is very small, and hence the danger to which rash operators may be exposed during its distillation. Hence, also, it is unnecessary to surround the receiver with cold water, as when alcohol and most other liquids are distilled. Indeed the application of cold to the bottom of the receiver generally causes it, in the present operation, to crack. By the above method, I have made the concentrated oil of vitriol flow over in a continuous slender stream, without the globe becoming sensibly hot.

"I have frequently boiled the *distilled* acid till only one-half remained in the retort; yet at the temperature of 60° Fahrenheit, I have never found the specific gravity of acid, so concentrated, to exceed 1.8455. It is, I believe, more exactly 1.8452. The number 1.850, which it has been the fashion to assign for the density of pure oil of vitriol, is undoubtedly very erroneous, and ought to be corrected. Genuine *commercial* acid should never surpass 1.8485; when it is denser, we may infer sophistication, or negligence, in the manufacture."

If the acid of commerce contain dissolved sulphate of lead, it becomes turbid on dilution, so that its remaining clear when mixed with water is some proof of its purity, as far at least as lead is concerned. The simplest mode of judging of the purity of this acid is to introduce a given weight into a platinum capsule, and evaporate it; if it leaves more than one per cent. of solid residue, it has probably been intentionally sophisticated.

When sulphuric acid was procured by the distillation of green vitriol, it was frequently observed that a portion concreted into a white mass of radiated crystals. The same substance has also been remarked as occasionally formed in the acid of the English manufacturers. It has been called *glacial* or *fuming sulphuric acid*, and is considered as the pure or anhydrous acid. When crystallized green vitriol or protosulphate of iron is exposed to a dull red heat, it crumbles down into a white powder, and loses the greater part of its water of crystallization. (See *Sulphate of Iron.*) In this state it is put into a coated earthen or green glass retort, and gradually exposed to an intense red or even white heat: a dark-coloured acid liquor distils over, of a specific gravity of about 1.89, which smokes when exposed to air, from the escape of the highly volatile *dry* sulphuric acid, which is united in the brown liquid with a portion of hydrated acid.

The dry or *anhydrous sulphuric acid* may be separated from the brown liquid, by careful distillation from a retort into a dry and cold receiver; it passes over in drops, which concrete on cooling into a tenacious crystalline mass. This acid is liquid, at a temperature above 66°; and at 78° its specific gravity, according to Bussy, is 1.97. (*Journal de Pharmacie,*

x. 368.) When it has once congealed it is difficult to fuse it, because the first portions heated become vapour, and propel the rest forward; by slight pressure, however, this may be prevented. When kept in a temperature between 75° and 80° it gradually liquefies. At a temperature somewhat above this, which, however, has not been accurately determined, it passes into the state of colourless vapour. In the absence of all moisture, it has no action upon litmus paper. It dissolves sulphur, forming brown, green, or blue compounds, according to the quantity taken up; when water is added, the sulphur is deposited. It also dissolves iodine, forming with it a blue-green solution. Passed through a red-hot porcelain tube, anhydrous sulphuric acid is resolved into one volume of oxygen and two of sulphurous acid. Caustic lime or baryta heated in its vapour, become ignited, and converted into sulphates. The attraction of this anhydrous acid for water is such as to produce intense heat, and a hissing noise, when small portions of it are thrown into that fluid; and if any quantity of it be added to such a proportion of water as is required to convert it into hydrated acid, they combine, according to Berzelius, with heat, light, and explosion.

The liquid acid from sulphate of iron yields about one-fourth its weight of anhydrous acid by distillation; but if this cannot be procured, the anhydrous acid may be obtained, according to Berzelius, by the distillation of such other sulphates as easily part with their acid: those sulphates, which require a very elevated temperature, are less fit for the purpose, because the acid is then apt to be resolved into sulphurous acid and oxygen. Bisulphate of soda or persulphate of iron may thus be employed. The former may be made by mixing in a crucible three parts of thoroughly desiccated sulphate of soda with two of common sulphuric acid, and heating them till the ebullition occasioned by the escape of water has ceased. The resulting dry mass is then to be pulverized, transferred to a porcelain retort, and distilled at a red heat; the acid which passes over may be collected in a receiver cooled by ice: it is generally of a dark colour, which appears to arise from dust accidentally present. A persulphate of iron, applicable to the same purpose, may be procured by mixing finely powdered peroxide of iron into a thin paste, with common sulphuric acid, and gradually heating it (below redness) till they combine into a saline mass, which is to be powdered and subjected to distillation as before. The acid thus obtained generally contains a little water, and if it crystallizes, it forms brittle foliaceous crystals. Carefully distilled by a gentle heat, the anhydrous acid passes over, and common liquid acid (hydrated) remains in the retort.

The instantaneous solution of indigo by the fuming sulphuric acid is a remarkable and important property of it: the solution, at first deep purple, becomes blue by exposure to air, or by dilution.

It has long been an object with the manufacturer to obtain sulphuric acid without the aid of nitre, and a patent has been obtained for a process of this kind, invented by Mr. Hill. It consists in submitting coarsely powdered iron pyrites (bi-sulphuret of iron) to a red heat, in cylinders communicating with a leaden chamber containing water; part of the sulphur, as it burns out of the pyrites, appears at once to pass into the state of sulphuric acid.

Cases of poisoning by sulphuric acid are not unfrequent; the best antidotes are copious draughts of chalk and water, and of carbonate of magnesia and water.—(Orfila.)

Native Sulphuric Acid has been found by Professor Baldassari, in the cavities of a small volcanic hill, called Zoccolino, near Sienna.

When sulphuric acid is dropped into a concentrated and hot solution of iodic acid, a peculiar compound is formed, which may be termed *iodo-sulphuric acid;* it is yellow, fusible, and crystallizes on cooling in rhomboids; at a higher temperature it partly sublimes, and is partly decomposed.

Sulphuric Acid and Ammonia—Sulphate of Ammonia—may be obtained by passing ammonia into sulphuric acid; but it is usually prepared by saturating dilute sulphuric acid with *carbonate of ammonia*, or by decomposing muriate of ammonia by sulphuric acid. It is the *secret sal-ammoniac* of some old writers. This salt is important as a source of the muriate of ammonia, which is obtained by sublimation from a mixture of common salt and sulphate of ammonia; by this process sulphate of soda is also formed.

Sulphate of ammonia, in its driest state, retains, according to Dr. Ure, one proportional of water, and consists of

Sulphuric acid	40
Ammonia	17
Water	9
	66

By crystallization it affords six-sided prisms; soluble in two parts of water at 60°; and containing, according to Berzelius, one proportional of dry sulphate, = 57 + 2 proportionals of water = 18. Its taste is bitter and pungent. When heated, it melts and in part sublimes, ammonia is given off, and a *super-sulphate* remains, consisting of 2 proportionals of acid + 1 of alkali.

Native Sulphate of Ammonia is sometimes found in volcanic products; it occurs in stalactitic concretions of a whitish or yellowish colour, and covered with a white efflorescence: it has thus been procured from fissures in the earth surrounding certain small lakes in Tuscany, near Sienna; and among the products of Etna and Vesuvius; it has been termed by Karsten *Mascagnine*, from the name of its discoverer.

Hyposulphurous Acid.—This, which appears to be the first step in the oxydizement of sulphur, is a body which cannot be preserved in the insulated state. Some of its compounds have been long known, and long ago described, under the name of *sulphuretted sulphites;* but the existence in these of a peculiar and definite acid of sulphur is a more recent discovery, arising out of the researches of Gay-Lussac, Thomson, and Herschel. Higgins and Berthollet found that iron and zinc might be dissolved in aqueous sulphurous acid, without any evolution of hydrogen gas, and that they formed peculiar colourless crystallizable salts, which, acted upon by certain other acids, evolved sulphurous acid and sulphur. By exposing hydrosulphuret of soda in solution to the air, Vauquelin obtained an analogous compound of soda. Gay-Lussac first suggested the existence of a peculiar acid composed of sulphur with a minimum of oxygen, in these compounds, in 1813; and they were afterwards examined with much precision and ability by Herschel. (*Ed. Phil. Jour.* i. 8 and 36.) This acid has not been obtained in a separate state, though Berzelius has suggested the probability of its existence in some of those peculiar coloured compounds of anhydrous sulphuric acid and sulphur, which have been above adverted to. When we attempt to decompose its compounds in the humid way, sulphurous acid escapes, and sulphur is precipitated.

Hyposulphurous acid is formed when sulphites are digested in close vessels, with sulphur, or when solutions of the sulphurets of the alkaline bases are exposed to the air till they become colourless: it is also produced by the action of zinc or iron filings upon the solution of sulphurous acid in water, and from these salts it may be transferred to several other bases. In the first case, the oxygen of the sulphurous acid divides itself between the original and the newly added sulphur. In the latter, the zinc or iron combine with half the oxygen of the sulphurous acid; and the other half, remaining in combination with the sulphur, forms the new acid: it is composed, therefore, of—

$$\left.\begin{array}{lll}1 \text{ Proportional of sulphur} & . \quad . & = 16 \\ 1 \quad ,, \quad \text{oxygen} & . \quad . & = \ \ 8\end{array}\right\} = 24$$

Hyposulphuric Acid was discovered in 1819 by Gay-Lussac and Welther. It was accidentally formed in an attempt to analyse the oxide of manganese by the employment of sulphurous acid, when a peculiar salt was formed, which did not precipitate baryta. This salt was afterwards found to contain a peculiar acid of sulphur, to which Gay-Lussac gave the above name. It is obtained by passing a current of sulphurous acid through a mixture of finely powdered and pure peroxide of manganese and water. A solution is obtained, which is filtered and thoroughly agitated and digested with hydrated baryta, which must be added in small excess. The sulphuric acid and the greater part of the oxide of manganese are thus precipitated. The solution is again filtered and evaporated till it crystallizes, and the crystals are a second time dissolved and obtained by evaporation, in order to procure them free from manganese; they are then dried, powdered, weighed, and dissolved in water; and to every hundred parts of the dissolved salt, 18.78 parts of sulphuric acid, of the specific gravity of 1.84, diluted with four parts of water, are added. The baryta is thus thrown down in the state of sulphate, and the new acid remains in solution. Having been filtered, it is to be concentrated by exposure under the exhausted receiver of the air-pump including a vessel of sulphuric acid, till it acquires the density of 1.347. If its exposure and evaporation be continued beyond this point, it is resolved into sulphuric and sulphurous acids. A temperature of 212° effects the same change in its composition. It is sour, and reddens vegetable blues.

Neither oxygen, nor chlorine, nor nitric acid, nor peroxide of manganese, affect the composition of hyposulphuric acid at common temperatures; it dissolves zinc with the evolution of hydrogen, and hyposulphate of zinc results. It saturates the salifiable bases, and with lime, baryta, strontia, and protoxide of lead, it forms soluble compounds, whereas those formed by these bases with the sulphuric acid are difficultly soluble or insoluble. These salts, however, are not permanent at high temperatures, but when heated they are resolved into sulphates, with the escape of sulphurous acid: notwithstanding this they remain neutral, though the quantity of sulphurous acid which escapes is such as would itself have saturated the base. This singular acid, therefore, appears to be composed of one proportional of sulphur, and two and a half of oxygen, or more correctly, in reference to its saturating powers, of two proportionals of sulphur and five of oxygen; thus:

$$\left.\begin{array}{lcc r}\text{2 Sulphur} & . & . & (16 \times 2) = 32 \\ \text{5 Oxygen} & . & . & (\ 8 \times 5) = 40\end{array}\right\} = 72$$

These numbers correspond with one proportional of sulphurous, = 32, and one of sulphuric acid, = 40; but the compound only saturates single proportionals of bases.

Sulphur and Chlorine—Chloride of Sulphur.—This compound was first described by Dr. Thomson, in 1804 (Nicholson's *Journal*, vol. vii.); and afterwards more fully examined by Berthollet, Junior. (*Mem. d'Arcueil*, t. i.) When sulphur is heated in chlorine, it absorbs rather more than twice its weight of that gas. Ten grains of sulphur absorb 30 cubic inches of chlorine, and produce a liquid of a greenish-yellow, by transmitted light, but red by reflected light, consisting of 16 sulphur + 36 chlorine, and represented, therefore, by the number 52. (Davy, *Elements*, p. 280.) The combination also takes place at common temperatures, and may be effected by passing chlorine through a tube containing powdered sulphur. It exhales suffocating and irritating fumes when exposed to the air. Its specific gravity is 1.6: it is volatile below 200°. It does not affect dry vegetable blues; but when water is present, it instantly reddens them, sulphur is deposited, and sulphurous, sulphuric, and muriatic acids are formed in consequence of a decomposition of the water. It dissolves sulphur and phosphorus, and decomposes ammonia. It also decomposes alcohol and ether, and is decomposed by mercury, heat being evolved, sulphur deposited, and chloride of mercury formed.

Sulphur and Iodine readily unite by a gentle heat, and form a black crystallizable compound, first described by M. Gay-Lussac.—*Ann. de Chim.*, 91. It is decomposed by a degree of heat a little exceeding that required for its formation. It is probably a compound of one proportional of each of its components.

Sulphur and Bromine—Bromide of Sulphur.—When bromine is digested with sulphur, a red liquid compound results, which emits fumes when exposed to air, and has little action upon dry litmus paper, but powerfully reddens it, when moist. It is slowly acted on by cold water, but at 212° the action is violent, sulphuretted hydrogen is evolved, and hydro-bromic and sulphuric acids are formed. Chlorine decomposes the bromide of sulphur, and chloride of sulphur is formed, with the evolution of bromine.

Sulphur and Hydrogen—Sulphuretted Hydrogen Gas—Hydrothionic Acid—Hydrosulphuric Acid.—This compound of sulphur and hydrogen was discovered by Scheele in 1777. It may be obtained by presenting sulphur to nascent hydrogen, which is the case when sulphuret of iron is acted upon by dilute sulphuric acid. It may also be conveniently obtained by heating bruised sulphuret of antimony in muriatic acid; or one part of flowers of sulphur and two of iron filings may be made into a thin paste with water, and heated in a flask till the mixture blackens, after which the addition of sulphuric acid diluted with four times its bulk of water, causes an abundant evolution of sulphuretted hydrogen. (*Ann. de Chim. et Phys.* vii. 314.)

Sulphuretted hydrogen is gaseous at common temperatures and pressures. Under a pressure of about 17 atmospheres at 50°, Mr. Faraday found it to assume the liquid form: it is then limpid, and apparently possessed of a refractive power exceeding that of water; when a tube containing it was opened under water, it instantly and violently rushed forth under the form of gas. (*Phil. Trans.* 1823, p. 92.)

Sulphuretted hydrogen gas may be collected over water, though, by agitation, that fluid absorbs nearly thrice its bulk. It has a peculiarly nauseous fetid odour, resembling that of rotten eggs, and so diffusible, that a single cubic inch escaping into the atmosphere of a large room, is soon everywhere perceptible by its smell. Its specific gravity to hydrogen is as 17 to 1. 100 cubic inches weigh 36 grains. Its specific gravity compared with air is as 1.180 to 1; and compared with hydrogen, as 17 to 1. It is inflammable, and during its slow combustion, sulphur is deposited, and water and sulphurous acid formed. It extinguishes the flame of a taper. When respired, it proves fatal; and it is very deleterious, even though largely diluted with atmospheric air. According to the statement of Dupuytren and Thenard, a small bird died immediately in air containing only one 1500th of sulphuretted hydrogen; one 800th killed a middle-sized dog; and a horse perished in an atmosphere containing one 150th. It exists in some mineral waters.

The aqueous solution of sulphuretted hydrogen is transparent and colourless when recently prepared, but it gradually becomes opalescent, and if exposed to air it deposits sulphur, and the greater part of the gas escapes. It is an exceedingly delicate test of the presence of most of the metals, with which it forms coloured precipitates. Dr. Henry found that one measure of sulphuretted hydrogen mixed with 20,000 measures of hydrogen, carburetted hydrogen, or atmospheric air, produces a sensible discolouration of white lead or of oxide of bismuth, mixed with water, and spread upon a piece of card. In this way we may ascertain the presence in coal gas of extremely small quantities of sulphuretted hydrogen, and may even form an estimate of its proportion when too minute to be otherwise measured, by comparing the shade of colour with a series prepared for the purpose, by exposing slips of card covered with white lead and water to mixtures of sulphuretted hydrogen, and common air in known proportions. (*Elements,* i. 431.)

It reddens infusion of litmus; and as it combines with the greater number of salifiable bases, it has by some been regarded as an acid. Gay-Lussac has termed it *hydrosulphuric acid.*

When 1 volume of sulphuretted hydrogen and 1.5 of oxygen are inflamed in a detonating tube, 1 volume of sulphurous acid is produced, and water is formed. Thus the sulphur is transferred to 1 volume of the oxygen, and the hydrogen to the half volume. Sulphuretted hydrogen, therefore, consists of 16 sulphur + 1 hydrogen, and its number is 17. Sulphuretted hydrogen may also be decomposed by the Voltaic flame, in the apparatus shown at page 146, or by a succession of electric sparks. Its volume is unchanged, but the sulphur is thrown down. The gas, therefore, may be regarded as consisting of one volume of hydrogen and one volume of the vapour of sulphur, condensed into one volume, as in the following symbols :—

Hydrogen	Sulphur		Sulphuretted Hydrogen
1	16	=	17

100 cubical inches of hydrogen weigh . .	2.118	grains
100 cubical inches of sulphur vapour . .	33.888	„
100 cubical inches of sulphuretted hydrogen	36.006	

This specific gravity closely approximates to the original experimental determination of Sir H. Davy.

Chlorine and iodine instantly decompose sulphuretted hydrogen ; sulphur is deposited, and muriatic and hydriodic acids are formed. Nitric acid poured into the gas occasions a deposition of sulphur, and nitrous acid and water are formed with considerable elevation of temperature. The aqueous solution of the gas is also decomposed by these re-agents.

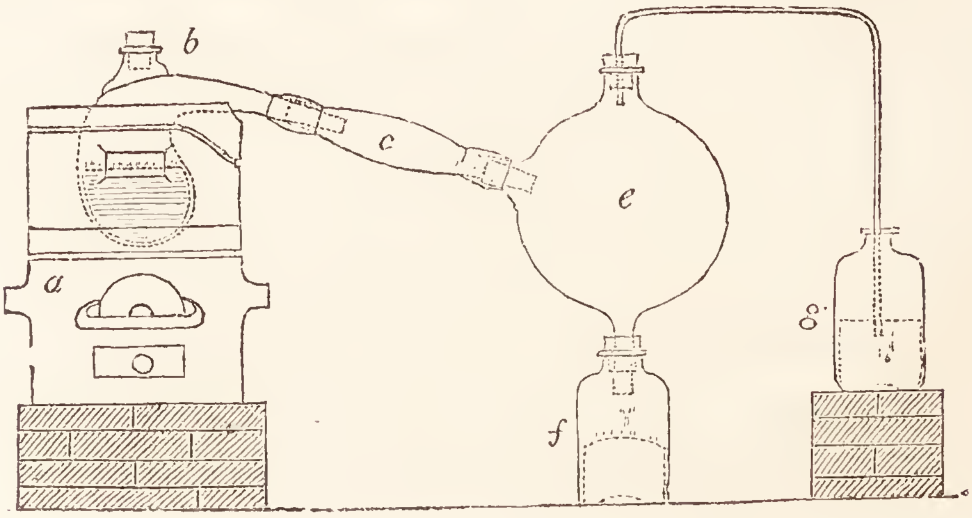
When sulphuretted hydrogen is mixed with its volume of nitric oxide over mercury, a diminution of bulk ensues, in consequence of the production of water ; sulphur is deposited and nitrous oxide remains in the vessel.

When two volumes of sulphuretted hydrogen are mixed in an exhausted balloon with one of sulphurous acid, they mutually decompose each other, occasioning the production of water, and the deposition of sulphur ; if the gases be perfectly dry, the action is slow. According to Thomson, the deposited matter is not sulphur, but a compound of sulphur, oxygen, and hydrogen, which he calls *hydrosulphurous acid.* (*Ann. of Phil.* xii. 441.)

When potassium or sodium are heated in sulphuretted hydrogen, sulphurets of those metals are formed with vivid combustion, and pure hydrogen is liberated. When tin or lead are fused in the gas, they also decompose it, and absorb the sulphur, leaving a volume of hydrogen equal to that of the original gas. Passed over metallic oxides, water and metallic sulphurets are the results. The different oxides effect this decomposition at very different temperatures.

Sulphuretted hydrogen and ammonia readily unite, and produce *Hydrosulphuret of Ammonia.* At first, white fumes appear, which become yellow, and a yellow crystallized compound results. If this be obtained by the condensation of 1 volume of sulphuretted hydrogen and 2 of ammonia, it may be considered as consisting of 1 proportional of each of its components, or of 17 sulphuretted hydrogen + 17 ammonia = 34. It is of much use as a test for the metals, and may also be procured by passing sulphuretted hydrogen through an aqueous solution of ammonia.

A compound of sulphuretted hydrogen and ammonia, with excess of sulphur, is obtained by distilling a mixture of about four parts of slaked quicklime, two of muriate of ammonia, and one of sulphur. The following is the disposition of the apparatus for this experiment: *a*, a small furnace; *b*, a tubulated earthen retort containing the above materials; *c*, an adapting tube; *e*, a glass balloon for condensing the vapour; *f*, a receiver; *g*, a bottle of water, into which the glass tube, issuing from the



upper part of the receiver *e*, is made to dip about half an inch.

The product in the bottle *f* may be mixed with the water in *g*, and the whole used for washing out the receiver *e*. In its concentrated state, this compound exhales white fumes, as was first remarked by Boyle, whence it was termed *Boyle's Fuming Liquor*, or *Volatile Liver of Sulphur*. It is a deep yellow liquid, smelling like a mixture of sulphuretted hydrogen and ammonia. When kept in common white glass vessels, it renders them brown or black, in consequence of its action on the oxide of lead which the glass contains.

According to Gay-Lussac, no ammonia is decomposed in the above operation, the requisite hydrogen being obtained from the muriatic acid, and partly from the water.

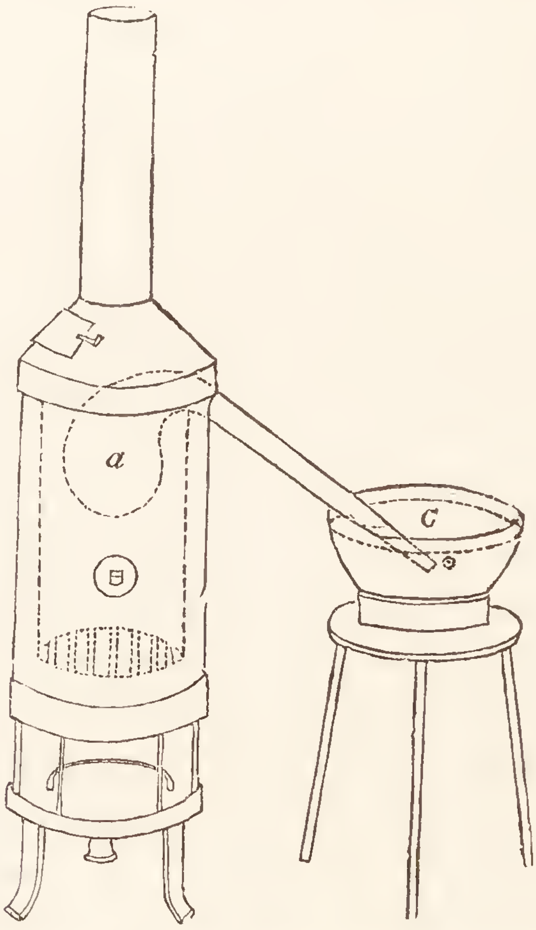
Bi-sulphuret of Hydrogen. — Another compound of hydrogen and sulphur, which has been called *supersulphuretted hydrogen*, is a liquid formed by dropping a strong solution or bisulphuret of potassium into dilute muriatic acid (see *Sulphurets of Potassium*): it probably consists of two proportionals of sulphur $= 32 + 1$ of hydrogen $= 1$. If the acid be dropped into the sulphuretted solution, sulphuretted hydrogen escapes, and sulphur is precipitated; but proceeding as above directed, the greater part of the sulphur remains united to the hydrogen, and a peculiar yellow oily liquid (bisulphuret of hydrogen) is the result. It is heavier than water. The success of the experiment depends much upon the state of concentration of the alkaline solution, which should neither be too strong nor too dilute, and should be slightly warm, and stirred during the mixture.

Sulphur and Nitrogen do not form any definite compound, though the nitrogen evolved during the decomposition of certain animal substances often seems to contain sulphur.

Sulphur, in its ordinary state, always contains hydrogen, which it gives off during the action of various bodies for which it has a powerful attraction. Thus, if equal weights of sulphur and copper, or iron filings, be introduced into a retort, and heated, a portion of sulphuretted hydrogen is evolved at the period of their combination. When potassium and sulphur are heated together, a vivid combustion ensues, and sulphuretted hydrogen is evolved. Berzelius, by heating sulphur with oxide of lead, remarked the formation of water, but in such small and indefinite quantities, as induced him to adopt the generally received opinion, that the presence of hydrogen is accidental, and that it is not an element of sulphur.

Section IV. Phosphorus.

Phosphorus is obtained by distilling concrete phosphoric acid with half its weight of charcoal, at a bright red heat. This mixture is put into the coated earthen retort *a*, placed in the small portable furnace *b*; the tube of the retort should be immersed about half an inch into the basin of water *c*. A great quantity of gas escapes, some of which is spontaneously inflammable, and when the retort has obtained a bright red heat, a substance looking like wax, of a reddish colour, passes over. This, which is impure phosphorus, may be rendered pure by melting it under warm water, and squeezing it through a piece of fine shamoy leather; but great care must



be taken that none adheres to the nails or fingers, which would inflame on taking them out of the water, and produce a painful and troublesome burn. It is usually formed into sticks, by pouring it, when fluid, into a glass tube under water.

In performing this distillation, a high temperature is required, so that the furnace should be sufficiently capacious to hold a body of charcoal piled up above the retort, which, as earthenware becomes permeable to the vapour of phosphorus at a red heat, must be coated with a mixture of slaked lime and solution of borax; this mixture may be laid on with a brush, in two or three successive coats, and forms an excellent *vitrifiable lute.*

When pure, phosphorus is nearly colourless, or of a pale buff colour, semitransparent, and flexible at common temperatures, but at 32° brittle. Its specific gravity is 1.770. It melts, when air is excluded, at 105°. If suddenly cooled after having been heated to 140°, it sometimes becomes black; but if slowly cooled, always remains colourless. At 550° it boils, air being excluded, and rapidly evaporates in this form of colourless vapour. It may thus be purified by careful distillation, but the process is troublesome and dangerous. Dr. Henry gives the following directions for the process:—The proper quantity of phosphorus should first be put into the retort, with a sufficient portion of water to cover it. The water must then be made hot enough to melt the phosphorus, which, on cooling, forms a mass, of the shape of the bottom of the retort. When cold, fill the retort with water, and invert it in water. Displace the water by hydrogen gas, forced from a bladder through a bent pipe; keep the finger on the open end of the retort neck; place it in a sand bath; and immerse the mouth of it in water. Then apply heat very cautiously. A bladder should also be provided, furnished with a stop-cock and pipe, and filled with hydrogen. During the distillation, the gas in the retort is absorbed, and it is necessary to add more from the bladder, otherwise the water will rush into the retort, and occasion an explosion. By distillation in this mode, phosphorus is rendered much purer. In the neck of the retort a substance is condensed of a beautiful red or carmine colour, which is a combination of carbon and phosphorus, or a *phosphuret of carbon.* Thenard observes that phosphorus, however frequently distilled, cannot be freed entirely from charcoal, a minute quantity of which does not impair its whiteness or transparency. When fused with about half its weight of sulphur, and suffered to cool gradually, a part of the phosphorus separates in rhombic dodecaedral crystals. It may also be crystallized by slowly cooling a saturated solution of it in naphtha. When exposed to air, it exhales luminous fumes, having a peculiar alliaceous odour: this arises from a slow combustion; hence the necessity of preserving it in water. It is tasteless, and insoluble in water, but proves poisonous when taken into the stomach.—Orfila, *Traité des Poisons*, II., P. ii. p. 186.

Retained for some time in contact with water, phosphorus decomposes it; oxide of phosphorus, and, probably, phosphorous and phosphoric acids, are formed, and phosphuretted hydrogen is emitted. Mr. Phillips has observed, that these changes are most rapid when light has free access. (*Ann. of Phys.* v.) According to Berzelius, light, and especially violet light, has the peculiar effect of reddening phosphorus under whatever circumstances it is exposed to its influence; in nitrogen gas, the solar rays readily fuse it, but in hydrogen and in vacuo, they cause it to sublime in red scales. There are several peculiar circumstances respecting the luminosity and inflammability of phosphorus. When exposed to the air at temperatures above the freezing point, it shines in the dark with a pale blue light, which increases in intensity with the temperature. This appears to arise from a very slow combustion, attended by the production of acid: it ceases in close vessels as soon as the greater part of the oxygen has been absorbed; and is said not to take place when the air has been artificially dried: in this case the requisite formation of phosphorous acid seems to be prevented. In pure oxygen, phosphorus is not luminous till heated to between 70° and 80°, above which it becomes very luminous, and soon inflames. Oxygen, and most other gases, in which phosphorus has been immersed, acquire its odour, and when mixed with air become slightly luminous. According to Dr. Henry, if a piece of phosphorus be introduced into a vessel of oxygen gas over mercury, at a temperature not exceeding 80°, no perceptible absorption will happen in twenty-four hours; but if, the temperature remaining the same, the pressure be diminished to one-eighth or one-tenth that of the atmosphere, the phosphorus will be surrounded with white vapours, will become luminous in the dark, and will absorb oxygen. Under ordinary pressures, a higher temperature is required for this effect; but if the density of the oxygen be reduced in the above proportion by mixing it with nitrogen, hydrogen, or carbonic acid, the phosphorus becomes luminous.

In the vacuum of the air-pump, phosphorus in small pieces, loosely enveloped in cotton, will generally inflame and burn for a time with a pale light: under the same circumstances it more readily kindles if sprinkled with powdered resin or sulphur; alone, it does not inflame. Berzelius remarks, that the water in which phosphorus has been kept in perfectly closed vessels, acquires a luminous property when agitated; this is not the case when air has access.

The temperature at which phosphorus inflames has been variously stated. According to Dr. Higgins, when perfectly dry, a temperature of 60° is sufficient. It easily takes fire by the heat of the hand and slight friction, or when rubbed upon a piece of coarse paper: it requires therefore to be handled and wiped with the utmost caution. Owing to the superficial formation of phosphorous and phosphoric acid, when it burns imperfectly at low temperatures, its further combustion is often prevented: thus, in rubbing a fragment of phosphorus between two pieces of brown paper, a momentary combustion often ensues, and it requires considerable friction to cause it again to inflame; for the same reason it is very difficult to light a piece of paper by the flame of phosphorus, for the paper becomes covered and protected by the acid.

At a temperature of about 100°, phosphorus takes fire, and burns with intense brilliancy, throwing off copious white fumes. If, instead of burning phosphorus with free access of air, it be heated in a confined portion of very rare air, it enters into less perfect combustion, and three compounds of phosphorus with oxygen are the result, each characterized by distinct properties. The first is a red solid, less fusible than phosphorus; the second is a white substance, more volatile than phosphorus; the third, a white and more fixed body.

The red solid consists of a mixture of phosphorus and oxide of phosphorus. *Oxide of phosphorus* is the white substance with which phosphorus becomes incrusted when kept for some time in water. It is very inflammable, and less fusible and volatile than phosphorus. It is this substance which is generally used in the *phosphoric match-boxes.* To prepare it for this purpose, a piece of phosphorus may be put into a small phial, and melted and stirred about with a hot iron wire, so as to coat its interior. A portion of the phosphorus is thus oxidized by its imperfect combustion, and a small quantity, taken out upon the end of a brimstone match, instantly inflames upon coming into the contact of the air.—(Nicholson's *Journal*, vi. 134.)

Phosphorus and Oxygen.—Besides the oxide of phosphorus, which has just been alluded to, there are three *acid* compounds of phosphorus and oxygen, which have been termed *hypophosphorous, phosphorous,* and *phosphoric* acids.

Hypophosphorous Acid was discovered by M. Dulong (*Annales de Chimie et Physique*, vol. ii. p. 141). It is prepared as follows: Upon 1 part of *phosphuret of barium* pour 4 parts of water, and when the evolution of phosphuretted hydrogen gas has ceased, pour the whole upon a filter. To the filtered liquid add sulphuric acid as long as any precipitate forms; separate the precipitate, which is a compound of sulphuric acid and baryta, and the clear liquor now contains the hypophosphorous acid in solution. When concentrated by evaporation, a sour viscid liquid is obtained, incapable of crystallization, and eagerly attractive of oxygen.

Rose obtained pure hypophosphorous acid by boiling hydrate of baryta with water and phosphorus, till all garlic odour ceased, filtering the liquid and decomposing it by excess of sulphuric acid; separating the precipitate and digesting the clear fluid for a short time with excess of oxide of lead; then filtering the sulphate of lead from the solution of hypophosphite, and decomposing the latter by a current of sulphuretted hydrogen. The acid freed from the precipitate was concentrated until of sufficient strength. (*Annalen der Physik und*

Chemie, 1828, p. 77.) When this acid is heated, it is decomposed with the evolution of phosphuretted hydrogen and phosphorus; phosphoric acid is the residue: in the above state, therefore, the hypophosphorous acid evidently contains combined water.

Hypophosphite of Ammonia.—This salt is extremely soluble, very deliquescent, very difficultly crystallizable, and soluble in alcohol. These characters appertain more or less to all the hypophosphites.

Phosphorous Acid.—The volatile white substance above mentioned as one of the products of the combustion of phosphorus in rarefied air, is this acid in a dry state: by burning phosphorus in a tube with very limited access of air, and caution as to temperature, it may easily be collected in the form of a white volatile powder, which, when exposed to air, rapidly absorbs moisture, becomes hot, inflames, and burns into phosphoric acid. It rapidly dissolves in water, has a sour taste, reddens vegetable blues, and combines with certain of the salifiable bases to form salts called *phosphites.* When acted upon by such of the metallic oxides as readily part with their oxygen, it is converted into phosphoric acid, and the oxide is reduced.

The phosphorous acid in combination with a definite proportion of water, forming what Sir H. Davy termed *hydrophosphorous acid,* is obtained by mixing protochloride of phosphorus with water: a mutual decomposition of the liquids ensues, and muriatic acid and phosphorous acid result; the former is easily driven off by heat, and, on carefully evaporating the remaining solution, a crystallizable compound is obtained, of a sour taste, and very soluble in water, which by heat is resolved into phosphoric acid and bi-hydroguret of phosphorus. (See *Phosphuretted Hydrogen.*)

Phosphoric Acid may be formed by burning phosphorus in excess of oxygen. There is intense heat and light produced, and white deliquescent flocculi line the interior of the receiver. It is produced in the same way by burning phosphorus under a dry bell-glass in atmospheric air. For this purpose, a piece of phosphorus in a watch-glass or small porcelain capsule may be placed upon a plate of glass, and covered over with a tall receiver; when inflamed, it burns at first furiously, but the combustion gradually subsides for want of oxygen, and may be renewed by gently lifting the receiver off the glass-plate: thus the whole of the phosphorus may be gradually burned; and it forms a quantity of dense smoke, which subsides in the form of snowy flakes: this is *Anhydrous Phosphoric Acid.* If a little water be dropped upon it, it dissolves with a hissing noise, and much heat is evolved, but it is some time before the whole dissolves into a clear liquid. It is also soluble in alcohol.

Phosphoric acid may also be obtained by acting upon phosphorus by nitric acid: in this case, if the action be at all intense, a portion of ammonia is at the same time produced, which is found in the state of phosphate of ammonia in solution. About six parts of nitric acid, specific gravity 1.4, are introduced into a tubulated retort placed in a sand heat, with a tubulated receiver luted on to it, the stopper of which should be open. When the acid is warm, drop into it gradually and carefully one part of phosphorus in small pieces; red nitrous vapour is instantly disengaged, and when its evolution ceases, put the stopper loosely into the receiver, and distil till the residue in the retort acquires the consistence of syrup; pour it into a platinum crucible, and give it a dull red heat: it fuses and concretes, on cooling, into a transparent substance, which is *Hydrated Phosphoric Acid,* and which retains water with great avidity, even at red heat, and at very high temperatures slowly volatilizes. The relative quantity of water which the acid thus retains is variously stated. It amounts, according to Dulong, to 17 per cent.; according to Rose, to between 9 and 10 per cent. only.

For the purpose of procuring phosphorus, phosphoric acid is most economically obtained by the decomposition of *bone earth,* which consists chiefly of phosphate of lime. The following is the mode of proceeding:—

On 20 pounds of calcined bone, finely powdered, pour 20 quarts of water, and 8 pounds * of sulphuric acid, diluted with an equal weight of water. Let these materials be stirred together, and simmered for about 6 hours. Let the whole be then put into a conical bag of linen to separate the clear

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* Pelletier and Dalton recommend twice the above quantity of sulphuric acid.

liquor, and wash the residuum till the water ceases to taste acid. Evaporate the strained liquor, and when reduced to about half its bulk, let it cool. A white sediment will form, which must be allowed to subside; the clear solution must be decanted, and boiled to dryness in a glass vessel. A white mass will remain, which may be fused in a platinum crucible, and poured out into a clean copper dish. A transparent *glass* is obtained, consisting of phosphoric acid with some phosphate, and a little sulphate of lime, commonly known under the name of *glacial phosphoric acid*. It yields phosphorus when distilled at a bright red heat with charcoal, and may be used as a source of pure phosphoric acid, which it affords by saturating its solution with carbonate of ammonia, filtering, evaporating to dryness, and exposing the residue to a red heat.

The hydrated phosphoric acid, when pure, readily dissolves in water, and deliquesces upon exposure to humid air into an intensely sour liquid, of a specific gravity = 2. It does not corrode the skin like nitric and sulphuric acids. Dr. Turner remarks (*Elements of Chemistry*), that it may be distinguished from all other acids by the following circumstances: that when carefully neutralized by pure carbonate of soda or potassa, it forms a solution in which no precipitate, or change of colour, is produced, when a stream of sulphuretted hydrogen gas is passed through it; but which is precipitated white by a solution of acetate of lead, and yellow by nitrate of silver: the first precipitate, the phosphate of lead, dissolves completely on the addition of nitric or phosphoric acid; the second, the phosphate of silver, is dissolved by both these acids and by ammonia.

The composition of these acids of phosphorus has been variously given by different chemists. Sir H. Davy's experiments upon this subject (*Phil. Trans.*, 1818) appear to me to furnish the least exceptionable results, and he has stated them thus:—

Hypophosphorous acid consists of Phosphorus	45,	Oxygen	15
Phosphorous acid	45	,,	30
Phosphoric acid	45	,,	60

If these numbers be reduced to the equivalents which I have employed, the number representing phosphorus would be 12, and the composition of the three acids of phosphorus would stand thus:—

			Phos.	Oxyg.	
Hypophosphorous acid,	2 phosphorus	+ 1 oxygen, or	24 +	8 =	32
Phosphorous acid .	1 „	+ 1 „	12 +	8 =	20
Phosphoric acid .	1 „	+ 2 „	12 +	16 =	28

But, according to the researches of Berzelius and of Dulong, the oxygen contained in the phosphorous and phosphoric acids is in the ratio of 3 to 5; and the latter acid consists of 44 phosphorus and 56 oxygen. Dr. Thomson's analysis of phosphate of lead, however, furnishes a result in favour of Sir H. Davy's estimate respecting the phosphoric acid; and the mutual action of water and chloride of phosphorus favour the opinion that the phosphorous acid consists of 1 proportional of each of its components, supposing Sir Humphry's experiments on the composition of that chloride as correct.

It has already been observed, that, when phosphorus is exposed to a moist atmosphere, it undergoes an apparent deliquescence, producing a sour liquid composed of phosphorous and phosphoric acids and water. M. Dulong called this *Phosphatic Acid*, under the idea of its being a peculiar and definite compound.

Phosphate of Ammonia is a common ingredient in the urine of carnivorous animals. It may be obtained pure by saturating phosphoric acid with ammonia, and carefully evaporating, so as to avoid the production of an acid salt. It forms octoëdral crystals soluble in two parts of water at 60°, of a bitterish saline taste, and insoluble in alcohol.

It consists, in the anhydrous state, of

$$\left.\begin{array}{l}\text{1 proportional of phosphoric acid} = 28 \\ \text{1 „ ammonia . .} = 17\end{array}\right\}45$$

According to Dr. Thomson, the rhombic crystals contain two proportionals of water, and consist, therefore, of 45 anhydrous phosphate + 18 water = 63.

Biphosphate of Ammonia is obtained by saturating the phosphoric acid obtained from bones by ammonia, boiling down to dryness, re-dissolving in water, and crystallizing: it forms prismatic crystals soluble in 5 parts of cold water, and containing, according to Berzelius, 25.36 per cent. of water; but Dr. Thomson says they are anhydrous, and consist of

2 proportionals of acid (28 × 2) = 56
1 „ ammonia . = 17
73

Subphosphate of Ammonia is described by Berzelius as obtained by adding caustic ammonia to a solution of the phosphate; it is difficultly soluble, and its concentrated solution forms a magma which, by exposure to air, loses its excess of alkali and becomes neutral.

Gay-Lussac has recommended the application of phosphate of ammonia to render muslin, and similar articles of clothing, to a considerable extent, incombustible. The goods are immersed in a solution of equal parts of phosphate and muriate of ammonia of a due strength, and then dried; upon applying flame to them, it will be found that they are burned with great difficulty, and cannot be consumed with flame, in consequence of the prevention of the access of oxygen by the glazing which the salts form at high temperatures.

The phosphates of ammonia are the best source of pure phosphoric acid; for, if they be exposed to a red heat in a platinum vessel, the ammonia evaporates, and the acid is obtained in the form of a transparent glass, very deliquescent and pure. The phosphate of ammonia for this purpose may be conveniently and economically prepared by saturating the impure acid obtained from bones with carbonate of ammonia, filtering and evaporating to dryness.

Phosphorus and Chlorine.—These elements unite in two proportions, forming two definite compounds, the *chloride* and *perchloride* of phosphorus.

When phosphorus is submitted to the action of chlorine in excess, it burns with a pale yellow flame, and produces a white volatile compound, which attaches itself to the interior of the vessel, and which is the *perchloride of phosphorus*. This substance was long mistaken for phosphoric acid, but its easy volatility is alone sufficient distinction; it rises in vapour at 200°. It is fusible under pressure, and crystallizable in transparent prisms; and when brought into the contact of water, a mutual decomposition is effected, and phosphoric and muriatic acids result. When passed through a red-hot porcelain tube with oxygen, phosphoric acid is produced and chlorine evolved, which shows that oxygen, at that temperature, has a stronger attraction for phosphorus than chlorine.

When phosphorus is burned in chlorine, one grain absorbs 8 cubic inches; so that the compound formed must be regarded as containing 1 proportional of phosphorus, and 2 of chlorine, or 12 of phosphorus + 72 of chlorine, and its number is = 84.

With ammonia, perchloride of phosphorus forms a singular compound, which, though consisting of three volatile bodies, remains unchanged at a white heat, and is insoluble in water. It is not altered, at common temperatures, by the acids or alkalis, and is only slowly decomposed when fused with potassa. This compound was discovered by Sir H. Davy (*Phil. Trans.* 1810, p. 233), and the examination of its remarkable properties formed an important step in that masterly train of inquiry which terminated in the demonstration of the simple nature of chlorine.

Chloride of Phosphorus, consisting of 12 phosphorus + 36 chlorine, is procured by distilling a mixture of phosphorus and *corrosive sublimate*, which is a perchloride of mercury. In this experiment *calomel*, or protochloride of mercury, is formed, and the phosphorus combines with one proportional of chlorine.

The chloride of phosphorus, when first obtained, is a liquid of a reddish colour; but it soon deposits a portion of phosphorus, and becomes limpid and colourless. It has a suffocating odour. Its specific gravity is 1.45. Exposed to the air it exhales acid fumes: it does not change the colour of dry vegetable blues. Its vapour is combustible. Chlorine converts it into perchloride. Ammonia separates phosphorus, and produces the singular triple compound before adverted to.

Chloride of phosphorus acts upon water with great energy, and produces muriatic and *phosphorous* acids, while the perchloride produces muriatic and *phosphoric* acids: for, as in the perchloride there are two proportionals of chlorine, so, in acting upon water, two of oxygen must be evolved, which, uniting to one of phosphorus, generate phosphoric acid. The chloride of phosphorus, on the contrary, containing only one proportional of chlorine, produces muriatic acid and phosphorous acid, when it decomposes water, as the following tables show:—

Before decomposition:

		Chloride of Phosp.			Water.
1 Chlorine	= 36	48	1 Hydrogen	= 1	9
1 Phosphorus	= 12		1 Oxygen	= 8	

After decomposition:

		Muriatic Acid.			Phosphorous Acid.
1 Chlorine	= 36	37	1 Phospho.	= 12	20
1 Hydrogen	= 1		1 Oxygen	= 8	

But the phosphorous acid, thus produced, always contains water, which it throws off when heated in ammonia, forming, with that alkali, a dry phosphite. This experiment shows that the *hydrophosphorous acid* consists of 2 proportionals of phosphorous acid = 40 + 1 water = 9.

Phosphorus and Iodine.—When these substances are brought together in an exhausted vessel, in the proportions of one part of phosphorus with eight or ten of iodine, they act violently, producing much heat but no light, and form a reddish or orange-coloured compound; this *iodide of phosphorus* decomposes water with great energy, and produces phosphorous and hydriodic acids. It appears to consist of 12 phosphorus + 125 iodine = 137.

Periodide of phosphorus is a black compound, formed by heating one part of phosphorus with rather more than 20 of iodine. It consists, according to Dr. Thomson, of 1 proportional of phosphorus + 2 of iodine; and, in decomposing water, produces hydriodic and phosphoric acids.

Phosphorus and Bromine.—According to M. Balard there are two bromides of phosphorus. When phosphorus and bromine are mixed in a flask filled with carbonic acid, they act intensely upon each other: heat and light are evolved, and a yellow crystalline substance rises to the upper part of the flask, whilst a liquid remains at the bottom. The latter is the *protobromide;* it is volatile, and emits pungent fumes when exposed to air. Water resolves it into hydrobromic and phosphorous acids. The crystalline *deutobromide* is converted, by a gentle heat, into a red liquid, and at a higher temperature into red vapour. It emits fumes when exposed to air, and, acted upon by water, forms hydrobromic and phosphoric acids.

Both these bromides are decomposed by chlorine with the evolution of bromine and the formation of chloride of phosphorus. Iodine, on the contrary, does not decompose them, but bromine decomposes the iodides of phosphorus.

Phosphorus and Hydrogen—Phosphuretted Hydrogen—Hydroguret of Phosphorus—Phosphorus may be heated, and even sublimed, in hydrogen gas, without the formation of any definite compound, although, under such circumstances, the gas retains a portion of the vapour of phosphorus, acquiring its peculiar odour, and becoming luminous in the dark when mixed with atmospheric air. When phosphorus is presented to nascent hydrogen, two gaseous compounds result. The one inflames spontaneously upon the contact of the atmosphere. This may be procured by heating phosphorus in a solution of caustic potassa; or by acting upon *phosphuret of lime* by dilute muriatic acid. In the former case about a quarter of an ounce of phosphorus should be introduced into a small retort, capable of holding about four ounces of water; it should then be completely filled with a moderately strong solution of potassa, and the beak being placed under the shelf of the pneumatic apparatus, the heat of an Argand lamp carefully applied till it boils: gas will gradually be generated so as to expel a portion of the alkaline solution, and ultimately to bubble up through the water. Upon coming into contact with the air, the bubbles inflame with a slight explosion; and if the atmosphere is still, each as it bursts produces a beautifully expanding ring of smoke, in consequence of the sudden formation of phosphoric acid and water.

If the retort, in which the gas is generated, contain common air, the first bubbles burn within the vessel, and the retort is frequently broken by the percussion, or by the rush of cold water from the trough, caused by the sudden expansion and subsequent contraction of the air within, an accident prevented by filling the retort with the liquid.

For obtaining this gas by the second process, Dr. Thomson gives the following directions:—Fill a small retort with water acidulated by muriatic acid, and then throw into it a quantity of phosphuret of lime in lumps. Plunge the beak of the retort under water, and place over it an inverted jar filled with that liquid. Phosphuretted hydrogen gas is extricated in considerable quantity, and soon fills the glass jar. Half an ounce of phosphuret of lime yields about 70 cubic inches of this gas.—Thomson's *System*, vol. i. p. 272.

This gas is colourless, has a nauseous odour like onions, a very bitter taste, and inflames when mixed with air, a property which it loses by being kept over water: water takes up about two *per cent.* of this gas, and acquires a bitter taste, and the smell of onions; but the solution has no acid properties like that of sulphuretted hydrogen.

When phosphuretted hydrogen is retained in dry vessels, or over mercury, and carefully excluded from light, it may be kept some time without alteration; but, in the contact of water, and exposed to light, it soon deposits a red film of phosphorus without changing its volume, and loses the property of spontaneous inflammability. It has been asserted, that in this case the gas deposits half of its phosphorus, and that a definite *subphosphuretted hydrogen* remains; but this statement requires further proof.

Houton Labilladiere has remarked, that bubbles of phosphuretted hydrogen sent up into a portion of common air standing over mercury, do not inflame when the air is compressed, or when the mercury is at the same level within and without the vessel; but that explosion immediately ensues when the confined air is rarefied by lifting up the jar, so that the column of mercury within may be above that without.

When bubbles of phosphuretted hydrogen are sent up into a jar of oxygen, they burn with greatly increased splendour; in chlorine, too, they burn with a beautiful pale blue light, forming muriatic acid and perchloride of phosphorus. In a narrow tube it may be mixed with oxygen without exploding, in which case it is deprived of its phosphorus without suffering any change of bulk. It burns when thrown up into nitrous oxide.

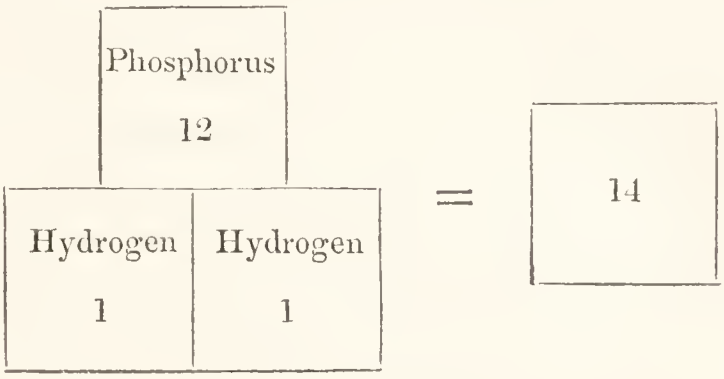
For our knowledge of the composition of this gas, we are chiefly indebted to Dr. Thomson, who has shown that the hydrogen suffers no change of bulk in uniting to the phosphorus; so that the difference of weight between this gas and pure hydrogen indicates the weight of phosphorus. Its specific gravity, compared with air, is as 0.902 to 1, and to hydrogen as 13 to 1: 100 cubic inches of phosphuretted hydrogen weigh 27.537 grains; hence the gas may be regarded as containing 1 proportional of phosphorus and 1 of hydrogen, or 12 + 1 = 13; or as consisting of 1 volume of hydrogen and 1 volume of phosphorus vapour, condensed into 1 volume of phosphuretted hydrogen.

Hydrogen	Phosphorus		Phosphuretted Hydrogen
1	12	=	13

When phosphuretted hydrogen is mixed with oxygen, it requires a volume and a half of the latter gas for its perfect combustion; and as the hydrogen would require half its volume of oxygen for the production of water, the remaining volume must unite to the phosphorus to produce phosphoric acid.

This view of the composition of phosphuretted hydrogen, founded upon Dr. Thomson's experiments, appears most consistent with analogy and theory; but its accuracy is questioned by M. Dumas (*Ann. de Chim. et Phys.*, xxxi. 153), who states that the decomposition of one volume of the gas affords one volume and a half of hydrogen: he also finds it considerably heavier than it is stated to be by Dr. Thomson: in short, the subject requires further investigation.

Bihydroguret of Phosphorus — Hydrophosphoric Gas.— The next compound of phosphorus and hydrogen has been called by Sir H. Davy, *hydrophosphoric gas.* It is procured by heating the solid hydrophosphorous acid in a very small retort. The gas must be collected over mercury, for water absorbs one-eighth its volume. Its specific gravity to common air is as 0.972 to 1, and to hydrogen is as 14 to 1. 100 cubical inches weigh 29.652 grains. It is not spontaneously inflammable, but explodes when heated with oxygen. It inflames spontaneously in chlorine, one volume requiring four of chlorine for its perfect combustion. Its smell is less disagreeable than the former. It consists of 2 proportionals of hydrogen and 1 of phosphorus, 2 hydrogen + 12 phosphorus = 14; but the 2 volumes of hydrogen are condensed into 1; consequently, when the gas is decomposed, as, for instance, by subliming sulphur in it, 2 volumes of sulphuretted hydrogen are formed. It may, therefore, be regarded as composed of 2 volumes of hydrogen and 1 volume of the vapour of phosphorus condensed into 1 volume of bihydroguret of phosphorus: thus,



When hydrophosphorous acid is decomposed for the production of this gas, phosphoric acid is always generated. Hydrophosphorous acid has been stated to contain 2 proportionals of phosphorous acid + 1 of water. Hence the elements,

$$\left.\begin{array}{r l} 24 & \text{phosphorus} \\ 16 & \text{oxygen} \end{array}\right\} = \text{phosphorous acid,}$$

$$\left.\begin{array}{r l} 8 & \text{ditto} \\ 1 & \text{hydrogen} \end{array}\right\} = \text{water,}$$

or 49 parts of hydrophosphorous acid contain

24 phosphorus
24 oxygen
1 hydrogen.

The 3 proportionals of oxygen = 24 will require one proportional and a half of phosphorus = 18, to form phosphoric acid; and the remaining half proportional of phosphorus will unite to the one of hydrogen to form hydrophosphoric gas.

To avoid fractions, the phenomena may be stated thus:— Four proportionals of hydrophosphoric acid contain

$$\begin{array}{l l r} 4 \text{ phosphorus} & . & = 48 \\ 4 \text{ oxygen} & . \quad . & = 32 \\ 2 \text{ oxygen} & \left\{\begin{array}{l} \text{in the} \\ \text{water} \end{array}\right\} & = 16 \\ 2 \text{ hydrogen} & & = 2 \end{array}$$

The whole of the oxygen, amounting to 6 proportionals (*i. e.* 8 × 6 = 48), unites to 3 proportionals of phosphorus (12 × 3 = 36), to form phosphoric acid. The 2 of hydrogen = 2, combine with the remaining proportional of phosphorus = 12 to form hydrophosphoric gas.

Grotthus has described a liquid compound of phosphorus and hydrogen, analogous probably to the corresponding combination of sulphur; and, if so, a *biphosphuret of hydrogen*, obtained by boiling phosphorus in an alcoholic solution of potassa. The phosphorus liquefies, and remains fluid when cold: if boiled in water, phosphuretted hydrogen is evolved, but no phosphoric acid is formed, nor is the water decomposed; and phosphorus, which concretes as usual, remains behind.

Phosphorus and Nitrogen produce no definite compound, though, in some cases of animal decomposition, the evolved nitrogen appears to hold phosphorus in solution.

According to Berzelius, when phosphorus is exposed to ammonia standing over mercury, a *phosphuret of ammonia* is produced of a dark colour, and pulverulent texture: its properties have not been examined.

Phosphorus and Sulphur may be readily united by fusion in an exhausted vessel. When one proportional of phosphorus is united to one of sulphur (12 + 16), the compound bears a high temperature without decomposition. It is a crystallizable solid at temperatures below 50°. (Faraday, *Journal of Science*, p. 361, vol. iv.) It is doubtful whether any other compound of these bodies exists, although they may be mixed by fusion in all proportions. If boiled in water, *phosphuret of sulphur* decomposes a portion of the fluid, often with explosion; and if kept in water at common temperatures, especially if exposed to light, sulphuretted hydrogen is evolved, and phosphorous acid is formed.

By acting upon fused phosphorus by the Voltaic spark, it always affords a small portion of hydrogen gas; this gas is also evolved from it, as from sulphur, during its union with some of the metals.

Section V. Selenium.

This rare and singular substance was discovered in 1818, by Professor Berzelius, during an examination of certain substances found in the sulphuric acid manufactured at Gripsholm, in Sweden. The sulphur used in these works is obtained from the iron pyrites of Fahlun, and the acid obtained from it deposits a red matter, which was supposed to contain tellurium, but the peculiarities of which were traced to a distinct and previously unknown substance, to which its discoverer gave the name of Selenium.

Some difference of opinion exists as to the place which selenium should occupy in our chemical arrangements. Berzelius includes it among the metals; but as it is a non-conductor of electricity, and a most imperfect conductor of heat, and as, in other respects, it bears much analogy to sulphur, I have followed the example of most of our systematic writers, and placed it among the non-metallic electro-positive combustibles.

Stromeyer and Rose have detected it in several metallic ores from the Hartz mines, and amongst some of the volcanic products of the Lipari islands; and it exists in some of the sulphurets of lead of Fahlun, and in the pyrites of the isle of Anglesey.

Selenium is most readily obtained by the decomposition of selenic acid, which may be effected by adding muriatic acid to its solution in water, and immersing a plate of zinc in the mixture: a grey or reddish-brown flocculent precipitate of selenium is then deposited. Berzelius, in his *Lehrbuch der Chemie,* has detailed the circuitous process by which he separated selenium from the red sediment of the Gripsholm sulphuric acid—(see also *Ann. of Phil.* xiv. 403) ; and M. Lewenau has described some important improvements in the modes of obtaining it in a pure state. (*Ann. of Phil. N. S.* viii. 104.)

Selenium, when cooled after fusion, has a reddish-brown colour, and complete metallic lustre ; its fracture is of a lead-gray colour, vitreous and metallic. Obtained from its solutions by precipitation upon zinc, it is red, but becomes black when boiled in water. A dilute solution of selenic acid mixed with sulphurous acid, and exposed to light, becomes covered with a film of reduced selenium of a gold colour. When fused, and very slowly cooled, its surface is gray and granular, without lustre ; its fracture dull, like that of metallic cobalt. Under certain circumstances, it assumes a prismatic crystalline texture, but not very distinct. In thin layers it is transparent, transmitting red rays ; it is softened by heat, becoming semifluid at 212°, and perfectly fusing at a temperature somewhat higher ; it remains for some time soft on cooling, and may be drawn out into filaments like sealing-wax, which are of a gray metallic lustre by reflected light, but by transmitted light of a clear ruby-red. Heated in a tube or small retort nearly to redness, it boils, and is converted into a yellow vapour of a deeper colour than chlorine, which condenses into black drops, that run together like quicksilver. Heated in the open air it rises in vapour, which may be condensed into a red powder. Its specific gravity is 4.3, and is characterized by tinging the flame of the blowpipe of a light blue colour, and by exhaling, when strongly heated, a peculiar and highly diffusible odour of decayed horseradish: it is brittle, soft, and easily reduced to powder.

Selenium and Oxygen.—These bodies appear to unite in three proportions, forming compounds which may be termed selenious oxide, and selenious and selenic acid.

Selenious Oxide is formed by heating selenium in a limited portion of atmospheric air, and washing the product to separate a portion of acid which is at the same time formed. The characters of this compound have not been accurately examined, nor has its composition been ascertained: it is sparingly soluble in water, and, passed through alkaline solutions, imparts to them its peculiar odour, but is not absorbed: it does not redden litmus.

Selenious Acid.—When a current of oxygen gas is passed over selenium, heated to its boiling point, it burns with a pale bluish-green flame, and this acid sublimes and condenses in long brilliant prismatic crystals, provided the vessel into which it is received is cold and capacious; otherwise, the sublimate is semifused and semitransparent: this is dry selenic acid; it loses its transparency by exposure to air, and rapidly absorbs water. Exposed to heat, the water separates again before the acid rises in vapour. Its taste is sour and hot; its odour, when sublimed, acrid, but not like that of the oxide. It is very soluble in warm water, and the solution furnishes crystals of hydrated acid. It also dissolves in alcohol, and the solution furnishes, on distillation, a liquid of an etherial odour. If this alcoholic solution be mixed with sulphuric acid, and then distilled, the product has an odour so insupportable, that Berzelius was unable to proceed in its examination.

Hydrated Selenious Acid is most readily obtained by boiling selenium in nitric or nitro-muriatic acid; it dissolves and is acidified, and, upon evaporation, may be obtained as a white residue.

The selenious acid and its salts may be decomposed by mixture with solution of sulphite of ammonia and the addition of an acid. Sulphurous acid is liberated, and the selenium is slowly reduced, the solution first acquiring a yellow colour, and in the course of some hours depositing red flocculi of selenium: this effect is accelerated by a boiling heat. This acid forms precipitates in the solutions of silver and of lead; its neutral salts with alkaline bases convert vegetable blues to green, and redden turmeric. It combines also in two and four proportionals with certain bases, so that it forms selenites, biselenites, and quadriselenites. It forms very few subsalts.

The proportion of oxygen in this acid is, to that contained in the bases to which it unites to form neutral salts, as two to one; so that it may be considered as a compound of one proportional of selenium and two of oxygen; the atomic weight of selenium thus deduced is 40, and this acid consists of

One proportional of selenium .	. .	=	40
Two proportionals of oxygen .	(8 × 2)	=	16
Equivalent of selenious acid .	.	=	56

Selenic Acid, in which one proportional of selenium is combined with three of oxygen, was first described by MM. Mitscherlich and Nitzsch. (*Ann. de Chim. et Phys.* xxxvi. 100.) This acid is obtained by fusing selenium, or selenious acid, or any of its salts, or a metallic seleniuret, with nitrate of potassa, or of soda: seleniuret of lead, as the most common ore containing it, has generally been used: it is to be digested in muriatic acid, to separate carbonates, and the residue mixed with its weight of nitrate of potassa or soda, and gradually thrown into a red-hot crucible; the fused mass is then well washed in hot water, which dissolves the alkaline seleniate and the nitrate: this solution, quickly boiled down, deposits seleniate of soda, and this being separated, the nitrate crystallizes on cooling; the mother liquor again boiled deposits more of the seleniate, and in this way the salts may be separated; for the seleniate, like sulphate of soda, is more soluble in water at about 180° than at 212°. The seleniate of soda thus obtained is not quite pure; it is to be mixed with muriate of ammonia and heated; nitrogen and water are evolved, selenium separated, and chloride of sodium formed: the selenium is now pure, and is to be converted by nitric or nitromuriatic acid into selenious acid, neutralized with soda, and this converted into seleniate by fusion with nitre, solution, and crystallization as before. The solution of this pure seleniate is decomposed by nitrate of lead; the insoluble seleniate of lead is well washed and diffused through water, into which a current of sulphuretted hydrogen is passed to precipitate the lead: the liquid is boiled, to evaporate excess of sulphuretted hydrogen, and is now dilute selenic acid. Its purity, as respects fixed bodies, is determined by its perfect volatility; if sulphuric acid be present, it may be ascertained by boiling a portion with muriatic acid, which produces selenious acid, and then testing by muriate of baryta, which should afford no precipitate.

Selenic acid is a colourless liquid, which may be heated to about 536° without decomposition; it is partially changed at higher temperatures; and at 554°, is rapidly resolved into selenious acid and oxygen. When concentrated, by exposure to a temperature of about 329°, it acquires a specific gravity of 2.524; at 513°, it is 2.6: it may be renderedsome what denser by evaporation at higher temperatures; but in that case a portion of selenious acid is formed in it; and it is impossible to expel the whole of its water without decomposition.

Selenic acid has a strong attraction for water, and evolves much heat when mixed with it; sulphuretted hydrogen does not decompose it, and hence that gas may be used to decompose some of the metallic seleniates. When boiled with muriatic acid, selenious acid and chlorine are produced, so that the selenio-muriatic acid dissolves gold upon the same principle as the nitro-muriatic. It dissolves zinc and iron with the evolution of hydrogen; and copper, with the production of selenious acid; it also dissolves gold, but not platinum; sulphurous acid, which decomposes selenious acid, has no action on selenic acid; so that to decompose selenic acid in this way, it must first be boiled with muriatic acid, which converts it into selenious acid, and the sulphurous acid, or a sulphite, then effects the separation of selenium.

From the resemblance, in crystalline form, of the seleniates to the sulphates, Mitscherlich inferred that the proportion of oxygen in selenic acid should correspond to that in sulphuric acid; that it should be to the base as three to one; and to that in the selenious acid as three to two. These views were confirmed by experiment; the selenic acid, therefore, consists of

One proportional of selenium	. . .	=	40
Three proportionals of oxygen	. (8 × 3)	=	24
Equivalent of selenic acid	. . .	=	64

In its affinity for bases, selenic acid is little inferior to sulphuric acid, for seleniate of baryta cannot be completely decomposed by sulphuric acid. Its laws of combination, however, require further investigation.

Selenium and Chlorine.—When chlorine is passed over selenium, it is absorbed with the production of heat, and a brown liquid *protochloride of selenium* results, not very volatile, heavier than water, and gradually resolved by the action of water into muriatic and selenious acids.

Exposed to excess of chlorine, the protochloride absorbs an additional quantity, and becomes converted into a white solid *perchloride*, which volatilises when heated, and condenses in the form of delicate crystals. It dissolves with the evolution of heat in water, producing a colourless sour solution, which probably contains muriatic and selenic acids.

The *iodide*, *bromide*, and *fluoride* of selenium appear not to have been examined.

Selenium and Hydrogen.—These bodies combine to form a gaseous compound termed *seleniuretted hydrogen* or *hydroselenic acid*. It may most easily be obtained by dissolving seleniuret of iron in muriatic acid. It readily dissolves in water, forming a solution at first colourless, but after a time acquiring a reddish hue: the solution smells and tastes somewhat like that of sulphuretted hydrogen; it reddens litmus, and permanently tinges the skin of a reddish brown. Nitric acid dropped into it occasions no change, and the gas does not readily escape from the water; but, when exposed to air, the solution gradually reddens; and deposits selenium. It occasions precipitates in all solutions of neutral metallic salts, which are black or dark-brown, with the exception of those from zinc, manganese, and cerium, which are flesh-coloured.

Seleniuretted hydrogen is easily decomposed by the joint action of air and water: it is absorbed by moist substances, and soon communicates to them a red colour. The selenium is thus remarkably deposited throughout the texture of organic bodies. A piece of moist paper is penetrated by the red colour. Moist wood, and even a thin piece of caoutchouc, became in the same way red throughout.

This gas exerts a dangerous action upon the trachea and organs of respiration; it inflames the eyes; and painfully stimulates the nasal membrane, destroying for some hours the sense of smell.

It consists of one proportional of each of its components, or 40 selenium + 1 hydrogen, and its equivalent is 41.

Selenium and Nitrogen have no mutual action, nor does selenium absorb ammonia; but when seleniuret of calcium and muriate of ammonia are mixed and distilled, a red fluid is obtained, of an hepatic odour, and decomposed by exposure to air, exhaling ammonia, and leaving selenium.

Selenium and Sulphur may be mixed by fusion in all proportions. An addition of about one per cent. only of sulphur renders selenium more red, fusible, and transparent when cold. A true *bisulphuret of selenium* may be obtained by passing sulphuretted hydrogen into selenious acid: the fluid becomes turbid, and acquires a fine yellow colour, but the precipitate is long in separating, unless a little muriatic acid be added: when warmed, it acquires a red colour and viscid texture, and may be distilled, without decomposition, at high temperatures. It is slowly acted upon by nitric acid, but nitromuriatic acid easily decomposes it: it is soluble in the caustic fixed alkalis, and in their hydrosulphurets, forming yellow solutions, from which acids precipitate it. Burned in the air, it at first exhales a sulphurous odour, but afterwards the smell of horseradish prevails. It consists, according to Berzelius, of 55.21 selenium and 44.79 sulphur, so that it may be regarded as containing

One proportional of selenium . . = 40
Two proportionals of sulphur . (16 × 2) = 32

Equivalent of bisulphuret of selenium . . = 72

Selenium and Phosphorus.—Dropped into melted phosphorus, selenium forms a red compound, apparently soluble in all proportions in the fused phosphorus. When phosphorus is saturated with selenium, an easily fusible compound results, which, on cooling, acquires a brown lustre and vitreous fracture. When this *phosphuret of selenium* is digested in water, a small portion of the phosphorus is oxidized, and the water acquires the odour of seleniuretted hydrogen, and deposits selenium when exposed to the air. The compound is dissolved when boiled in caustic potassa, and the solution contains phosphate and hydroseleniuret of potassa.

Section VI. Carbon.

The purest form of this elementary substance is the *diamond*, a mineral body first discovered in Asia, in the provinces of Golconda and Visapour in Bengal, and in the island of Borneo. About the year 1720 diamonds were first found in the district of Serra Dofrio, in Brazil. They always occur in detached crystals in alluvial soil. The primitive form of the diamond is the regular octoëdron, each triangular facet of which is sometimes replaced by six secondary triangles, bounded by curved lines; so that the crystal becomes spheroidal, and presents forty-eight facets. Diamonds, with twelve and twenty-four facets, are not uncommon. (Jamieson's *Mineralogy*, 2d edit. vol. i. p. 1.) The diamond has been found nearly of all colours: those which are colourless are most esteemed; then those of a decided red, blue, or green tint. Black diamonds are extremely rare. Those which are slightly brown, or tinged only with other colours, are least valuable. The fracture of the diamond is foliated, its laminæ being parallel to the sides of a regular octoëdron. It is brittle and very hard; its specific gravity is 3.5.

The art of cutting and polishing diamonds, though probably of remote antiquity in Asia, was first introduced into Europe in 1456, by Louis Berghen, of Bruges, who accidentally discovered, that, by rubbing two diamonds together, a new facet was produced. The particular process of forming the rough gems into *brilliants* and *rose diamonds* has been described at length by Jeffries. (*Treatise on Diamonds and Pearls,* 3rd edit., London, 1800.) By either of these processes, but especially by the former, so much is cut away, that the weight of the polished gem does not exceed half that of the rough stone; so that the value of a brilliant-cut diamond is esteemed equal to that of a similar rough diamond of twice the weight, exclusive of the cost of workmanship. The weight, and therefore the value of diamonds, is estimated in *carats,* 150 of which are about equal to one ounce troy, or 480 grains. They are divided into halves, quarters, or carat grains, eighth, sixteenth, and thirty-second parts.

The difference of value between one diamond and another is, generally speaking, as the squares of their respective weights: thus, the value of three diamonds, of one, two, and three carats' weight respectively, is as one, four, and nine. The average price of rough diamonds is estimated by Jeffries at 2*l.* per carat; and, consequently, when wrought, the cost of the first carat, exclusive of workmanship, will be 8*l.*, which is the value of a rough diamond of two carats.

		£.
A wrought diamond of	3 carats is worth	72
,,	4 ditto	126
,,	5 ditto	200
,,	10 ditto	800
,,	20 ditto	3,200
,,	30 ditto	7,200
,,	40 ditto	12,800
,,	50 ditto	20,000
,,	60 ditto	28,800
,,	100 ditto	80,000

This mode of valuation, however, only applies to small diamonds, in consequence of the difficulty of finding purchasers for the larger ones.

The largest known diamond is probably that mentioned by Tavernier, in the possession of the Great Mogul. Its size is about that of half an hen's egg; it is cut in the rose form, and when rough, is said to have weighed 900 carats. It was found in Golconda about the year 1550.

Among the crown jewels of Russia is a magnificent diamond, weighing 195 carats. It is the size of a small pigeon's egg, and was formerly the eye of a Brahminical idol, whence it was purloined by a French soldier; it passed through several hands, and was ultimately purchased by the Empress Catherine, for the sum of 90,000*l.* in ready money, and an annuity of 4000*l.*

Perhaps the most perfect and beautiful diamond hitherto found, is a brilliant brought from India by an English gentleman of the name of Pitt, who sold it to the Regent Duke of Orleans, by whom it was placed among the crown jewels of France. It weighs rather more than 136 carats, and was purchased for 100,000*l.*

Another form of carbon is *charcoal*, one of the purest varieties of which is *lamp-black.*

Charcoal may be prepared by heating pieces of wood, covered with sand, to redness, and keeping them in that state for about an hour. They are converted into a black brittle substance, which appears to be essentially the same, from whatever kind of wood it has been procured.

Common charcoal, employed as fuel, is usually made of oak, chestnut, elm, beech, or ash wood, the white and resinous woods being seldom used. Young wood affords a better charcoal than large timber, which is also too valuable to be thus employed. The billets are formed into a conical pile, which, being covered with earth or clay, is suffered to burn with a limited access of atmospheric air, by which its complete combustion, or reduction to ashes, is prevented.

Another, and a more perfect mode of preparing charcoal, consists in submitting it to a red heat in a kind of distillatory apparatus consisting of cast iron cylinders, from which issue one or more tubes for the escape of gaseous matters. The makers of gunpowder particularly prefer this process. (A plate of this apparatus is given by Mr. Parkes, in his *Chemical Essays.* See also *Prefatory History of Chemistry.*)

Lamp-black is prepared principally by turpentine manufacturers from refuse and residuary resin, which is burned in a furnace so constructed that the dense smoke arising from it may pass into chambers hung with sacking, where the soot is deposited, and from time to time swept off, and sold without any further preparation. (Aikin's *Dictionary*, Art. CHARCOAL.) When lamp-black has been heated red-hot in a close vessel, it may be considered as very pure carbon.

The quantity of charcoal obtained from different kinds of wood is liable to much variation. From 100 parts of the following woods, Messrs. Allen and Pepys obtained the annexed quantities of charcoal.—*Phil. Trans.* 1807.

Beech	15.00
Mahogany	15.75
Lignum vitæ	17.25
Oak	17.40
Fir	18.17
Box	20.25

Experiments on the relative quantities of charcoal and their specific gravities, as obtained from different woods, have also been made by Mr. T. Griffiths: the results will be found in the *Quarterly Journal*, xvi. 264. He also adverts to their different powers in conducting electricity.

Charcoal is a black, insoluble, inodorous, insipid, brittle substance; an excellent conductor of electricity, but a bad conductor of heat; unchanged by the combined action of air and moisture at common temperatures, and easily combustible in oxygen gas. It is capable of destroying the smell and taste of a variety of vegetable and animal substances. (Lowitz, *Crell's Annals*, vol. ii. p. 165.) The use of charring piles; of throwing charcoal into putrid water; of wrapping it in clothes that have acquired a bad smell; of adding it to port wine, with a view of making it tawny; depends upon the above properties. M. Bussy has published some interesting observations on the discolouring power of charcoal, in the *Journal de Pharmacie* for June, 1822, of which an abstract will be found in the *Quarterly Journal*, xiii. 406. It appears from his experiments, that certain physical conditions are requisite for the manifestation of this property, especially porosity and minute division, and that it is not possessed by any hard and brilliant charcoal even when finely powdered. Upon this principle, he accounts for the superior efficacy of the charcoal obtained by burning animal substances, over that of vegetables, in the destruction of colour. According to Payen, animal charcoal, boiled with lime-water, deprives it entirely of lime, an effect not produced by lamp-black or vegetable charcoal. (*Quarterly Journal*, xv. 384.)

Charcoal has generally been regarded as infusible. Upon this subject a series of experiments have been published by Professor Silliman, of which an abstract is given in the *Quarterly Journal*, xvi. 157.

Newly-made charcoal has the property of absorbing certain quantities of the different gases. Upon this subject the experiments of M. Theodore de Saussure are the most recent. (Thomson's *Annals*, vol. vi.) The charcoal was heated red-hot, then suffered to cool under mercury, and introduced into the gas. The following are the volumes of different gases absorbed by a volume of charcoal = 1.

Ammonia	90
Muriatic acid	85
Sulphurous acid	65
Sulphuretted hydrogen	55
Nitrous oxide	40
Carbonic acid	35
Bicarburetted hydrogen	35
Carbonic oxide	9.42
Oxygen	9.25
Nitrogen	7.5
Carburetted hydrogen	5
Hydrogen	1.75

The absorption was always at its maximum at the end of twenty-four hours.

The results of these experiments are widely different from those of Count Morozzo, (*Journal de Physique*, 1783,) and of M. Rouppe (*Ann. de Chim.* vol. xxxii.) It would also appear, that this property depends upon the mechanical texture of the charcoal, and consequently will vary in the different woods; for, by exposing the charcoal of different woods to air, Allen and Pepys found that they increased very differently in weight.

By a week's exposure, charcoal from

Lignum vitæ gained	9.6	per cent.
Fir	13.0	"
Box	14.0	"
Beech	16.3	"
Oak	16.5	"
Mahogany	18.0	"

The matter absorbed in these cases consisted principally of aqueous vapour, which is very greedily imbibed by newly-made charcoal.

Carbon and Oxygen.—Though these substances possess for each other a very powerful affinity, they do not combine at common temperatures: to this remark, however, there are, perhaps, some exceptions, and it appears that certain forms of carbon may exist, which produce carbonic acid whenever they come into contact with oxygen; these are, probably, peculiar to organic combinations.

There are two definite compounds of carbon and oxygen; the *carbonic oxides* and the *carbonic acid.*

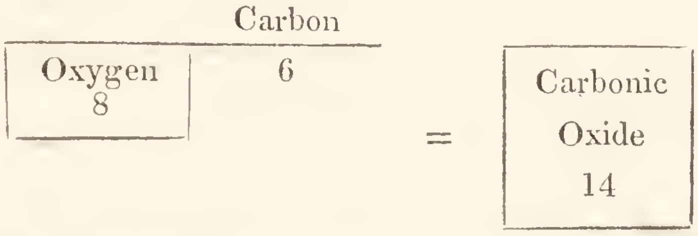
Carbonic Oxide, or *Gaseous Oxide of Carbon,* is usually obtained by subjecting carbonic acid to the action of substances which abstract a portion of its oxygen. Upon this principle, carbonic oxide gas is produced by heating in an iron retort a mixture of chalk and charcoal; or of equal weights of chalk and iron or zinc filings. It is also obtained by heating a mixture of equal parts of oxide of zinc and charcoal; but the mixture that affords it most pure is equal parts of carbonate of baryta and clean iron filings; these should be introduced into a small earthen retort, so as nearly to fill it, and exposed to a red heat: the first portion of gas being rejected as mixed with the air of the retort, it may afterwards be collected quite pure. The gas should be well washed with lime-water, and may afterwards be preserved over water. The nature of this gas was first made known by Mr. Cruickshank, of Woolwich, in 1802 (Nicholson's 4to *Journal,* v.); and about the same time it was examined by Messrs. Clement and Desormes.—*Ann. de Chim.* xxxix. 26.

Its specific gravity to hydrogen is as 14 to 1; and to atmospheric air as 0.972 to 1000; 100 cubical inches weighing 29.652 grains. It is fatal to animals, and produces giddiness and fainting when respired mixed with atmospheric air. (*Phil. Mag.* xliii. 367.) It extinguishes flame, and burns with a pale blue lambent light, when mixed with, or exposed to, atmospheric air. It has no taste, and little odour; it does not affect vegetable colours, occasions no precipitate in lime-water, and is very sparingly absorbed by water which has been deprived of air. Sir H. Davy found that the temperature of an iron wire heated to dull redness, was sufficient to inflame it.

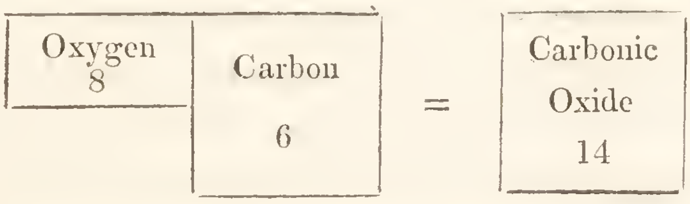
When a stream of carbonic oxide is burned under a dry bell-glass of air or oxygen, no moisture whatever is deposited, showing that it contains no hydrogen.

When two volumes of carbonic oxide, and one of oxygen, are acted on by the electric spark, a detonation ensues, and two volumes of carbonic acid are produced. Whence it appears, that carbonic acid contains just twice as much oxygen as carbonic oxide, which may be considered as a compound of half a volume of oxygen and one volume of gaseous carbon; or of one proportional of carbon and one of oxygen, the latter being so expanded as to occupy two volumes.

The representative number of carbon, as obtained by considering this gas a compound of one proportional, and one of oxygen, is 6; and 6 carbon + 8 oxygen = 14 carbonic oxide; or by volumes,



or,



And as 50 cubic inches of oxygen gas weigh . . 16.944 grains,
100 cubic inches of the vapour of carbon weigh 12.709

and 100 cubic inches of carbonic oxide . . = 29.653*

Carbonic oxide suffers no change by being passed and repassed through a red-hot porcelain tube; nor is it decomposed at high temperatures by phosphorus, sulphur, nor even, according to the experiments of Saussure, by hydrogen (*Journal de Physique*, lv.), though it is stated, upon other authorities, that at high temperatures hydrogen does decompose it.

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* Dr. Prout supposes that the same relation which has been shown to subsist between the atomic weights and volumes of the elementary gases, also holds good in respect to the vapours of other elements. Thus, in representing the atom of oxygen by half a volume, he assumes that the atoms of the other elements, such as iodine, sulphur, phosphorus, carbon, &c., correspond to an entire volume of their vapour. Hence he has deduced the following mode of calculating the specific gravity of the vapour of any substance from its atomic or combining weight. Multiply half the specific gravity of oxygen = 0.555, by the atomic weight of any of the elementary substances, and divide the product by the atomic weight of oxygen—the quotient is the specific gravity of the vapour: thus, to find the specific gravity of the vapour of carbon, as

$$8 : 6 :: 0.555 : 0.416;$$

8 being the equivalent, or atomic weight, of oxygen; 6 that of carbon; and 0.416 the specific gravity of carbon in the state of vapour.

When one volume of carbonic oxide is detonated with one of nitrous oxide, there result one volume of carbonic acid and one of nitrogen. (Henry, *Ann. of Phil.*, *N. S.*, viii. 299.) On this principle is founded a method of ascertaining the purity of nitrous oxide, it being implied, that that gas is free from nitric oxide. Let a given volume be exploded with slight excess of carbonic oxide,—if the nitrous oxide be pure, 100 measures of carbonic acid should be produced, and whatever is short of that proportion may be ascribed to impurity. None of the metals exert any action upon this gas, except potassium and sodium, which, at a red heat, burn in it by abstracting its oxygen, and carbon is deposited.

Dr. Henry found, that when a mixture of carbonic oxide with more than half its volume of oxygen is exposed over mercury in contact with spongy platinum, to a temperature between 300° and 310°, it begins to be converted into carbonic acid, and at a heat a few degrees higher, is quickly acidified. At common temperatures these mixtures are very slowly acted on. When carbonic oxide is added in an equal volume to a mixture of hydrogen and oxygen gases in explosive proportions, it prevents spongy platinum from causing detonation; but the gases slowly act on each other, and form water and carbonic acid. The platinum occasions mixtures containing less carbonic oxide to explode. (*Phil. Trans.*, 1824, p. 271.)

Carbonic Oxide and Chlorine.—These gases combine and produce *Chlorocarbonic Acid*, or *Phosgene Gas*, as it has been termed by its discoverer, Dr. John Davy, in consequence of the mode of its production.

By exposing a mixture of equal volumes of chlorine and carbonic oxide to the action of light, a condensation = 0.5 takes place. The compound has a peculiar pungent odour, not disagreeable when considerably diluted; it reddens litmus; it is soluble in water, and is resolved by it into carbonic and muriatic acid gases. Alcohol takes up 12 times its volume, and acquires a peculiar taste and the odour of the gas. The weight of chlorocarbonic acid to hydrogen is as 50 to 1, and to common air as 3.472 to 1. 100 cubical inches weigh 105.902 grains.

The following diagrams show its volume and that of its components.

Chlorine	Carbonic Oxide		Chlorocarbonic Acid
36	14	=	50

It condenses four times its volume of ammoniacal gas, producing a peculiar compound of a white colour, which is resolved by the action of water into muriate and carbonate of ammonia. Several of the metals, such as tin, zinc, antimony, and arsenic, when heated in this gas, decompose it, and absorb the chlorine: a volume of carbonic oxide, equal to the original volume of the chlorocarbonic acid, remains.—*Phil. Trans.*, 1807.

Carbonic Acid may be obtained by burning carbon, either pure charcoal or the diamond, in oxygen gas: the oxygen suffers no change of bulk, so that the composition of carbonic acid is learned by comparing its weight with that of an equal volume of pure oxygen. 100 cubic inches of oxygen weigh 33.8 grains: 100 cubic inches of carbonic acid weigh 46.5 grains: hence 100 cubical inches of carbonic acid must consist of 33.8 grains of oxygen, + 12.7 grains of carbon; and 1 proportional of charcoal = 6 + 2 proportionals of oxygen = 16 will constitute carbonic acid, represented by the number 22.

Assuming, upon the principle laid down by Dr. Prout (*Ann. of Philos.* vi. 321), that the specific gravity of the vapour of carbon is 0.416, it follows, that 100 cubic inches of its vapour, at mean temperature and pressure, would weigh 12.708 grains, and that 100 cubic inches of carbonic acid would consist of

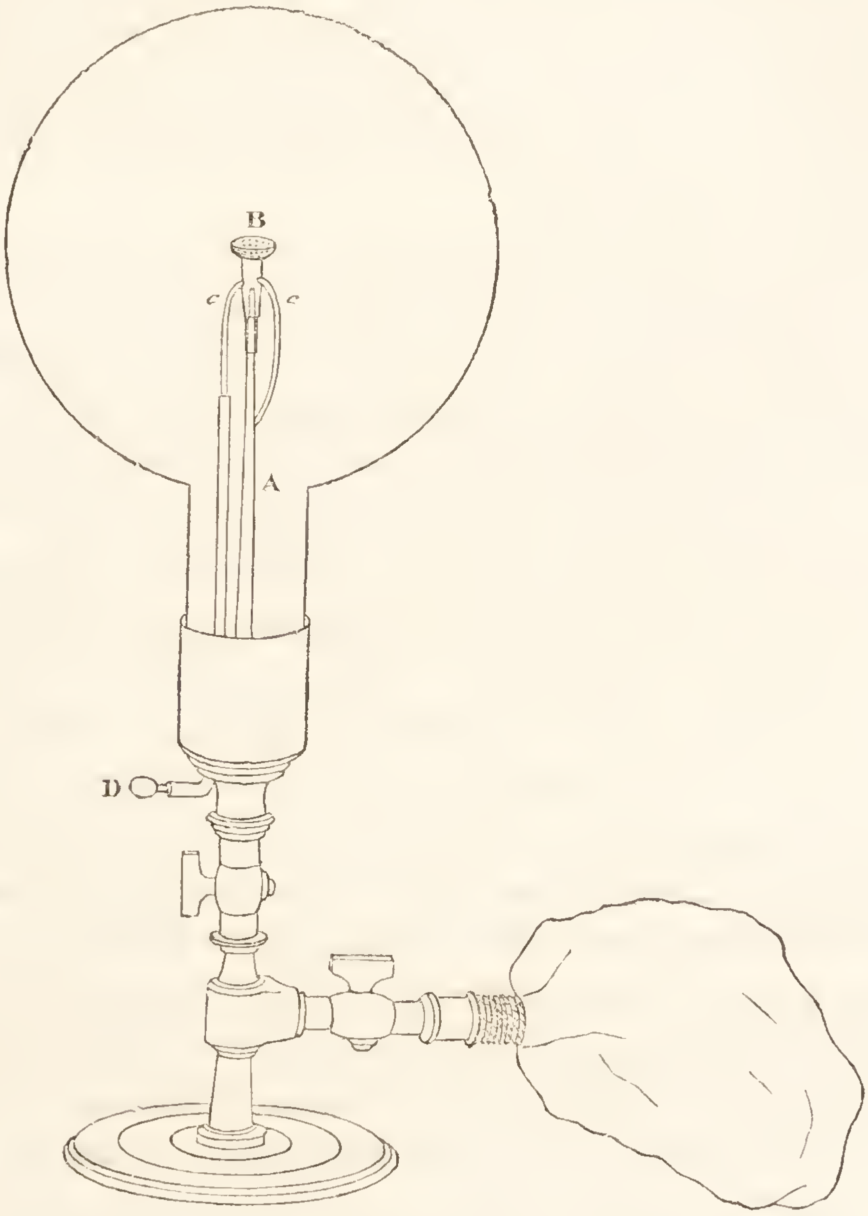
Vapour of carbon 100 cubic inches . .	=	12.708 grains.
Oxygen gas ditto	=	33.888
Weight of 100 cubic inches of carbonic acid	=	46.596

	Carbon	8 Oxygen		Carbonic Acid
or thus,	6	8	=	22

It is not evident to whom the combustibility of the diamond first occurred; but, in the year 1694, the Florentine Academicians proved its destructibility by heat by means of a burning lens. The *products* of its combustion were first examined by Lavoisier in 1772, and subsequently with more precision by Guyton Morveau, in 1785. (*Annales de Chimie*, xxxi.) In 1797, Mr. Tennant demonstrated the important fact, that when equal weights of diamond and pure charcoal were submitted to the action of red-hot nitre, the results were in both cases the same: and, in 1807, the combustion of the diamond in pure oxygen was found by Messrs. Allen and Pepys to be attended with precisely the same results as the combustion of pure charcoal. Hence the inevitable inference that charcoal and the diamond are similar substances in their chemical nature, differing only in mechanical texture.

When the diamond is heated in the flame of the blowpipe it soon begins to burn, and the combustion continues as long as the temperature is sufficiently high, but it does not produce heat enough, during its combination with the oxygen of the atmosphere, to maintain its combustion. If, whilst thus burning, it be introduced into a jar of pure oxygen, the combustion continues longer, but seldom till the whole is consumed: the best support for it, in this experiment, is a very small and thin platinum spoon, perforated with many holes; in this it may first be intensely heated by the oxygen blowpipe, and, whilst burning, carefully immersed into a bottle of pure oxygen gas containing a little lime-water: a good cork, through which the wire of the spoon passes, should secure the mouth of the bottle: it will thus go on burning brilliantly for some time, and the formation of carbonic acid be shown by the milkiness of the lime-water.

The combustion of the diamond may be most conveniently and perfectly effected by placing it upon a platinum capsule in a jar of pure oxygen inverted over mercury, and throwing upon it the focus of a burning lens. Sir H. Davy, when at Florence, in 1814 (*Phil. Trans.* 1814, p. 558), used for this purpose the same lens which was employed in the first trials on the action of solar heat on the diamond, instituted by Cosmo III., Grand Duke of Tuscany: he found that when strongly ignited by the lens in a thin capsule of platinum, perforated with many orifices so as to admit a free circulation of air, the diamond continued to burn in the oxygen, after being withdrawn from the focus, with so brilliant a light as to be visible in the brightest sunshine, and with very intense heat.

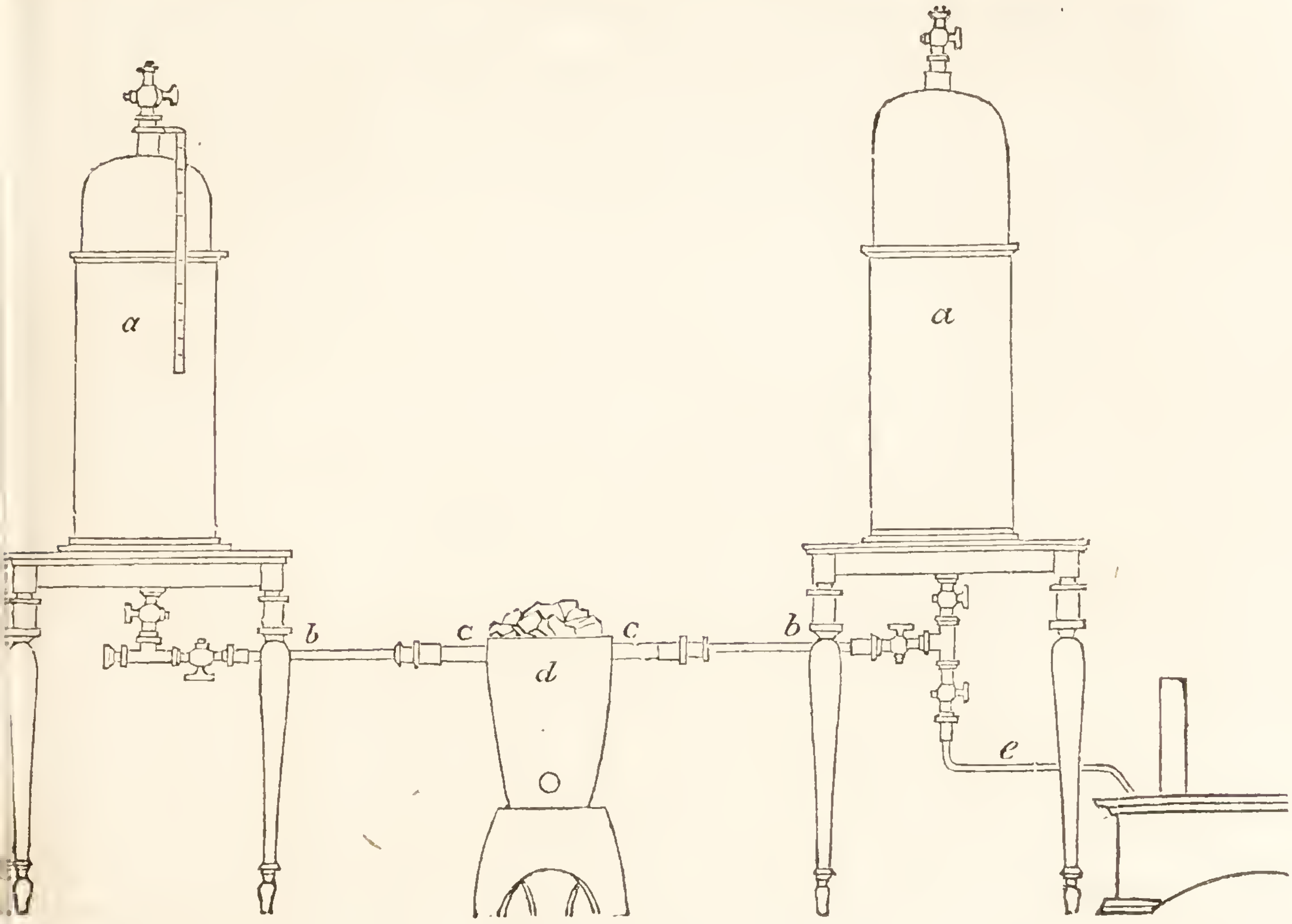


The following is a form of apparatus which may be conveniently employed for exhibiting the results of the combustion of the diamond. It consists of a glass globe, of the capacity of about 140 cubical inches, furnished with a cap, having a large aperture; the stop-cock, which screws into this cap, has a jet, A, rising from it, nearly into the centre of the globe; this is destined to convey a small stream of hydrogen, or other inflammable gas. Two wires, *c c*, terminate at a very little distance from each other, just above this jet, and are intended to inflame the stream of hydrogen by electrical sparks; one of them commences from the side of the jet, the other is inclosed and insulated nearly in its whole length in a glass tube: the tube and wire pass through the upper part of the stop-cock, and the wire terminates on the outside in a ball or ring, D, at which sparks are to be taken from the machine, either directly or by a chain. On the end of the jet is fixed, by a little socket, a small capsule, B, made of platinum foil. This capsule is pierced full of small holes, and serves as a grate to hold the diamonds. Its distance is about three-quarters of an inch from the end of the jet; and the arm, by which it is supported, is bent round, so that the stream of hydrogen shall not play against it. The stop-cock screws, by its lower termination, on to a small pillar, fixed on a stand, and at the side of this pillar is an aperture by which a bladder filled with gas may be connected with the apparatus.

On using the apparatus, the diamond is to be placed in the capsule; and then the globe being screwed on to the stop-cock, the latter is to be removed from the pillar and placed on the air-pump; the globe is then to be exhausted, and afterwards filled with pure oxygen; or, lest the steam of oxygen in entering should blow away the diamond, the globe may be filled with the gas first, and then, dexterously taking out the stop-cock for a short time, the diamonds may be introduced, and the stop-cock replaced. The apparatus is then to be fixed on the pillar, and a bladder of hydrogen gas attached to the aperture. Now, passing a current of sparks between the wires, a small stream of hydrogen is to be thrown in, which inflaming, immediately heats the capsule and diamonds white hot; the diamonds will then enter into combustion, and the hydrogen may be immediately turned off and the bladder detached. The diamonds will continue to burn, producing a strong white heat, until so far reduced in size as to be cooled too low by the platinum with which they lie in contact.

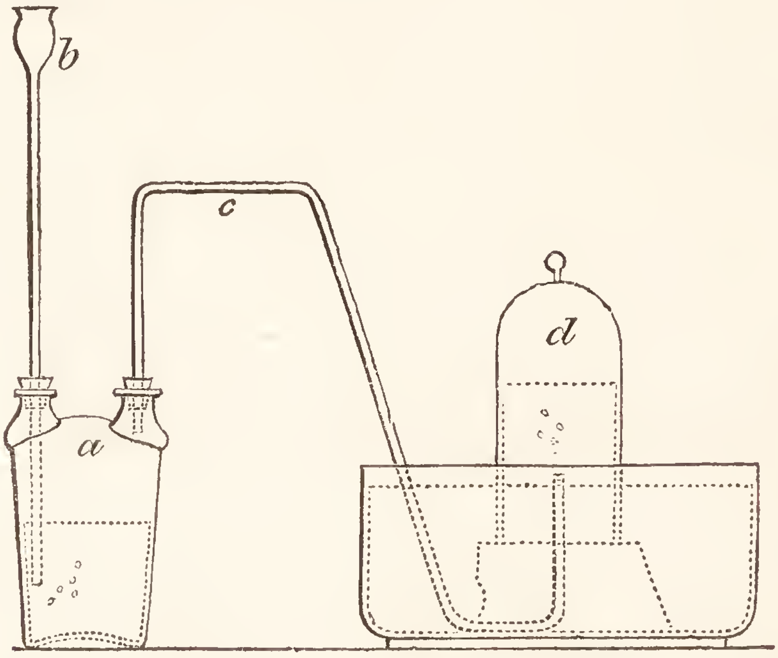
When the flame of hydrogen is used to heat the diamonds, it is evident a little water will be found in the globe, but this is of no consequence except in attempts to detect hydrogen in the diamond; the inconvenience may be obviated, if required, by using the flame of carbonic oxide. As, however, no hydrogen has at any time been detected in the diamond, it is better to use that gas as the heating agent; for then the carbonic acid, produced by the combustion, is unmixed with that from any other source, and may be collected, and its quantity ascertained.

The following method of illustrating the products of the combustion of the diamond was employed by Messrs. Allen and Pepys (*Phil. Trans.* 1807): *a a* are mercurial gasometers, one of which is filled with pure oxygen gas. The brass tubes *b b*, properly supplied with stop-cocks, issue from the gasometers, and are connected with the platinum tube *c c*, which passes through the small furnace *d*. *e* is a glass tube passing into the mercurio-pneumatic apparatus, by which the gas may be drawn out of the gasometers into convenient receivers. A given weight of diamond is introduced into the centre of the platinum tube, which is then heated to bright redness, and the gas passed over it, backwards and forwards, by alternately compressing the gasometers. Carbonic acid is soon formed, and it will be found that the increase of weight sustained by the oxygen is equivalent to that lost by the diamond; that the oxygen undergoes no change of bulk; and that the results are, in all respects, similar to those obtained by a similar combustion of perfectly pure charcoal.



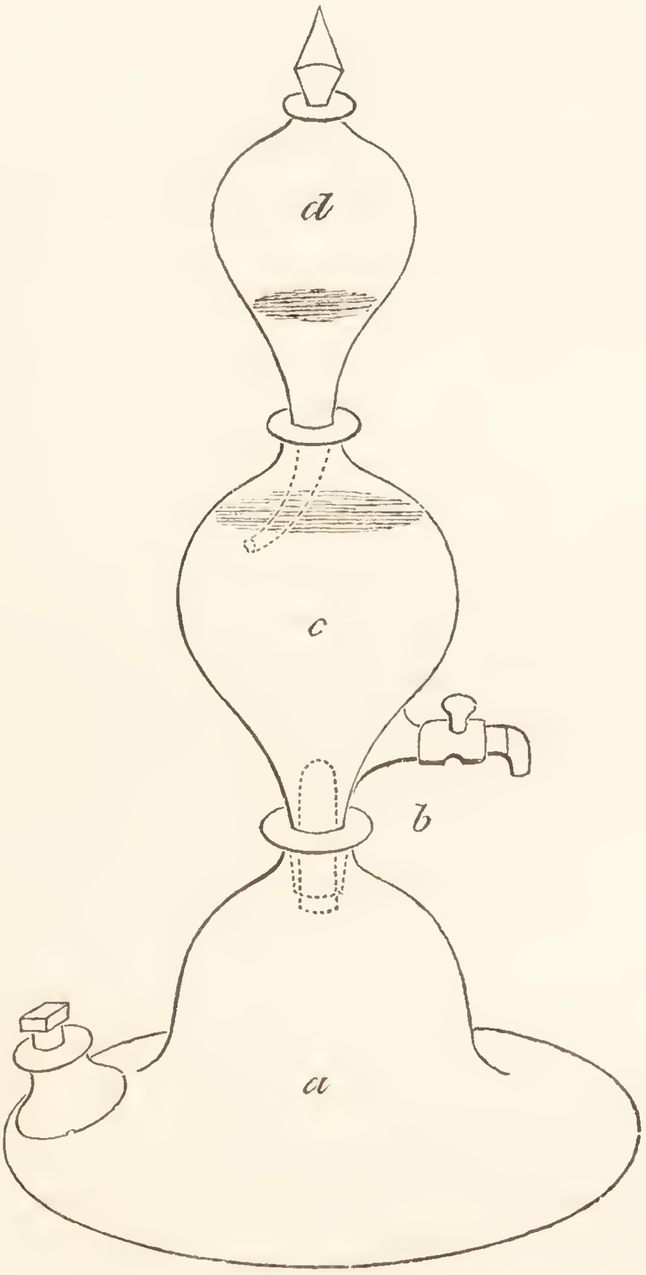
Carbonic acid is a most abundant natural product; [the best mode of procuring it for experiment consists in acting upon marble (*carbonate of lime*) by dilute muriatic acid.

For this purpose, the marble, in small fragments, is introduced into the two-necked bottle *a*, and covered with water; muriatic acid is then slowly poured down the funnel *b*, which causes an immediate effervescence, and the gas passes through the bent tube *c*, into the inverted jar *d*. When the action ceases, it may be renewed by the addition of fresh acid, until the whole of the marble is dissolved.



Carbonic acid may be collected over water, but must be preserved in vessels with glass-stoppers, since water, at common temperature and pressure, takes up its own volume, and acquires a specific gravity = 1.0015: under a pressure of two atmospheres it dissolves twice its volume, and so on. It thus becomes brisk and tart, and reddens delicate vegetable blues. If litmus paper, thus reddened, be exposed to the air, the blue colour returns as the acid evaporates; hence an easy distinction between the paper reddened by any of the more fixed acids, in which the change of colour is permanent. In the same way, infusion of litmus thus reddened becomes blue when the carbonic acid is expelled by boiling it. By freezing, boiling, or exposure to the vacuum of the air-pump, the gas is given off, and it gradually makes its escape when exposed to air, collecting in small bubbles upon the sides of the containing vessel, and passing off with especial rapidity when any foreign substances are thrown in, or when any substance is dissolved in the water: thus it is, that sugar added to soda-water, cyder, champagne, or other similar carbonated liquors, occasions in them an immediate and abundant effervescence.

The effervescent quality of many mineral waters is referable to the presence of this gas, and they are often imitated by condensing carbonic acid into water, either by a condensing pump, of which a description is given by Mr. Pepys (*Quarterly Journal of Science and Arts*, vol. iv. p. 305), or by a Nooth's apparatus, as represented in the following wood-cut. It consists of three vessels, the lowest, *a*, flat and broad, so as to form a steady support; it contains the materials for evolving the gas, such as pieces of marble and dilute muriatic acid, of which fresh supplies may occasionally be introduced through the stopped aperture. The gas passes through the tube *b*, in which is a glass valve opening upwards, into the vessel *c*, containing the water or solution intended to be saturated with the gas, and which may occasionally be drawn off by the glass stop-cock. Into this dips the tube of the upper-



most vessel *d*, which occasions some pressure on the gas in *c*, and also produces a circulation and agitation of the water. At the top of *d* is a heavy conical stopper, which acts as an occasional valve, and keeps up a degree of pressure in the vessels.

It has already been stated, that carbonic acid, though gaseous at all common temperatures and pressures, may be compressed into a liquid state. For this purpose Mr. Faraday proceeded as follows:—A strong tube, of about one-fourth of an inch diameter and eight inches long, being bent, at about two inches from its end, to an obtuse angle, and sealed at the shorter end, sulphuric acid was poured in through a small funnel, so as not to soil the larger leg, which was then loosely filled with fragments of carbonate of ammonia, and also hermetically sealed; the acid was then made to run upon the salt, and the evolved carbonic acid gradually appeared in the liquid form. The utmost precautions are here necessary to guard against explosion; such as goggles and a glass mask to preserve the face and eyes, and thick gloves for the hands: the tubes should also never be touched without great care; for sometimes, after having held the fluid safely for weeks together, they have exploded from some very slight increase of temperature. (*Phil. Trans.* 1823.)

Liquid carbonic acid is limpid, colourless, extremely fluid, and floats upon the other contents of the tube: it distils readily and rapidly at the difference of temperature between 32° and 0°. Its refractive power is much less than that of water. No diminution of temperature alters its appearance. In endeavours to open the tubes at one end, they always burst into fragments with powerful explosion. By inclosing a gauge in a tube, in which fluid carbonic acid was afterwards produced, it was found that its vapour exerted a pressure of 36 atmospheres at a temperature of 32°. Mr. Brunel has endeavoured to apply this liquid as a mechanical agent for the production of motive power. Of this attempt a short account will be found in the *Quarterly Journal* (Old Series, xxi. 131).

Carbonic acid is unrespirable, and when pure immediately suffocates an animal plunged into it. Atmospheric air mixed with a twentieth part of carbonic acid, is, however, respirable, for a short time, without inconvenience. Butterflies, and other insects, of which it is desired to preserve the colours unimpaired, may sometimes be conveniently suffocated by this gas. It extinguishes the flame of a taper. Its weight may be shown by placing a lighted taper at the bottom of a tall glass jar, and then pouring the gas out of a bottle into it, in the manner of a liquid; it descends, and extinguishes the flame, and will remain for some time in the lower part of the vessel. Like other gases, however, notwithstanding its specific gravity, it soon blends with, and diffuses itself through, the mass of surrounding air. In wells, and in some caverns, carbonic acid frequently occupies the lower parts, while the upper parts are free from it. The miners call it *choak damp*. In these cases it issues from crevices in the earth, and is produced by unknown sources.

In consequence of its weight, it may easily be collected without the pneumatic apparatus, as it issues from a tube passed to near the bottom of a dry bottle: it soon displaces the common air, and may be traced, flowing over the neck of the bottle, by holding a taper to it, which is then extinguished. (See this mode of collecting gas described at page 148.)

The presence of carbonic acid is instantly detected by *lime-water*, which it renders turbid, and causes a deposit of a white matter, which is *carbonate of lime*. The addition of water, saturated with carbonic acid, to lime-water, also occasions a milkiness from the same cause. If excess, either of the gas or of its aqueous solution, be added to the lime-water, the precipitate is re-dissolved, carbonate of lime being soluble in carbonic acid. (See *Lime.*)

As all common combustibles, such as coal, wood, oil, wax, tallow, &c., contain carbon as one of their component parts, so the combustion of these bodies is always attended by the production of carbonic acid. It is also produced by the respiration of animals; hence it is detected, often in considerable proportion, in crowded and illuminated rooms, which are ill ventilated, and occasions difficulty of breathing, giddiness, and faintness. In the atmosphere it may also be detected, as has already been mentioned (page 241). Saussure found it in air from the summit of Mont Blanc; and Humboldt discovered it in air brought by Garnerin from a height of many thousand feet, to which he had ascended in a balloon. Its production in the lungs is easily shown, by blowing the expired air through lime-water by means of a small tube: it becomes milky, and soon deposits carbonate of lime.

As carbonic acid is usually retained in combination by very feeble affinity, so it is evolved from most of the *carbonates* by the simple operation of heat. Thus chalk, when heated, gives out carbonic acid, and becomes *quicklime*. It is also evolved from its combinations by most of the other acids; and if dilute nitric, muriatic, or sulphuric acid be poured upon the carbonates, the presence of carbonic acid is indicated by *effervescence*.

Carbonic acid retards the putrefaction of the greater number of animal substances: applied to the roots of vegetables in aqueous solution, it is generally propitious to their growth, as will be more fully shown in a future Chapter. Most plants thrive in an atmosphere containing not more than a tenth or twelfth part of carbonic acid; and under certain circumstances, which will afterwards be explained, they decompose it, and evolve oxygen.

In page 301, the nature of carbonic acid has been synthetically demonstrated. It may be analyzed by the action of the metal *potassium*, which is capable of abstracting its oxygen, and, with the aid of heat, burns in it with great splendour; charcoal is deposited, and an *oxide of potassium* is formed. In this and in some other cases, oxygen is seen alternately producing acid and alkali. If carbonic acid, obtained by burning the diamond in oxygen, be thus decomposed by potassium, the carbon makes its appearance in the form of charcoal, equal in weight to the diamond consumed.

There are some other substances which, at high temperatures, are capable of decomposing carbonic acid, and abstracting part of its oxygen; thus, if a mixture of two parts of hydrogen and one of carbonic acid, by volume, be passed through a red-hot tube in the apparatus represented at page 222, water is formed, and carbonic oxide passes into the receiver *d*, mixed with the excess of hydrogen. Dr. Henry also found that by passing a succession of electric sparks through carbonic acid confined over mercury, a portion of it was resolved into carbonic oxide and oxygen. (*Phil. Trans.* 1809, 448.) When the carbonic acid which escapes decomposition has been washed out by solution of potassa, an electric spark inflames the residuary mixture, the oxygen and carbonic oxide again uniting and reproducing carbonic acid.

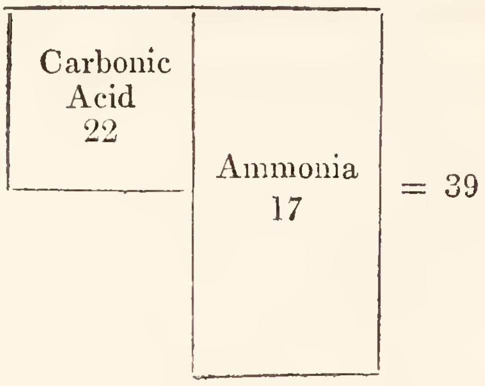
Phosphorus, when heated in carbonic acid, does not decompose it; whence it might be inferred, that carbon possessed a stronger affinity for oxygen than phosphorus, and such an inference is sanctioned by the decomposition of phosphoric acid, at high temperatures, by charcoal: but if complex attraction be brought into action, the case is altered, as was first shown by Mr. Tennant (*Phil. Trans.* 1791, p. 182), and afterwards by Dr. Pearson (*Phil. Trans.* 1792, p. 280). Thus it is, that certain carbonates are decomposed, at high temperatures, by phosphorus: if the vapour of phosphorus be passed over ignited carbonate of lime or carbonate of soda, charcoal is deposited, and phosphate of lime or phosphate of soda produced.

If carbonic acid be passed over red-hot charcoal, it becomes converted into carbonic oxide, by taking up an additional proportion of base. The blue flame, often seen upon the surface of a charcoal fire, arises from the combustion of the carbonic oxide formed in this way; the air entering at bottom, forms carbonic acid, which, passing through the red-hot charcoal, becomes converted into carbonic oxide.

At a bright red heat, iron and zinc decompose carbonic acid, by abstracting a portion of its oxygen, and forming oxide of iron or of zinc, and carbonic oxide.

Carbonic Acid and Ammonia—Carbonate of Ammonia.—These gases readily combine, and produce one of the most useful and best known of the ammoniacal compounds.

When one volume of carbonic acid and two volumes of ammonia are mixed in a glass vessel over mercury, a complete condensation ensues, and a *carbonate of ammonia* is produced. It consists of 17 ammonia + 22 carbonic acid, and is represented by 39. Provided the gases be quite dry they only condense each other in these proportions.

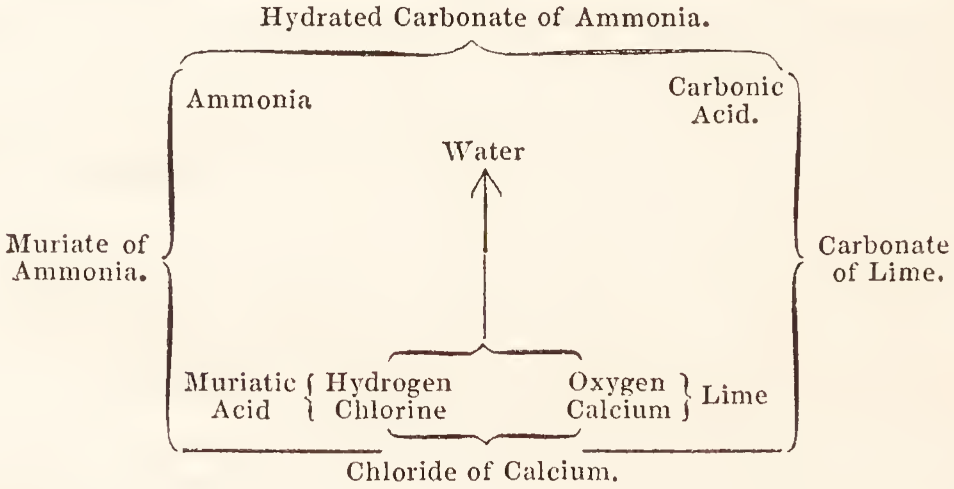


If one proportional of water be present, it so far overcomes the elasticity of the gas as to enable the salt formed to take up another volume of carbonic acid, and thus a *bicarbonate* is formed.

The *Carbonate of Ammonia of commerce* is generally met with in cakes broken out of the subliming vessel, being obtained by sublimation from a mixture of muriate of ammonia and carbonate of lime.

The results, however, of this decomposition are not, strictly speaking, carbonate of ammonia and muriate of lime, but carbonate of ammonia, water, and chloride of calcium, the two former being in combination, so that a *hydrated carbonate of ammonia* is always obtained.

Supposing the materials perfectly dry, the water is formed by the union of the hydrogen of the muriatic acid with the oxygen of the lime, as shown in the following diagram :



Mr. Richard Phillips has shown (*Quarterly Journal*, vii. 294) that this carbonate of ammonia, the *ammoniæ subcarbonas* of the *Pharmacopœia*, consists of

3	proportionals of carbonic acid	22 × 3 =	66
2	„ ammonia	17 × 2 =	34
2	„ water	9 × 2 =	18
			118

As far, therefore, as relates to the proportion of the carbonic acid to the ammonia, this salt is intermediate between the carbonate and bicarbonate; hence it may be termed a *sesquicarbonate of ammonia.*

Its odour is pungent; its taste hot and saline; it reddens turmeric, and renders blues green. A pint of water at 60° dissolves rather less than 4 ounces. This solution is directed in the *Pharmacopœia*, under the name of *Liquor Ammoniæ Subcarbonatis*. If a hot saturated solution of this salt be made in a close vessel, and suffered to cool, it deposits octoëdral crystals.

By exposure to air, sesquicarbonate of ammonia loses its odour, and then scarcely discolours turmeric paper. In this state it may be considered as an *hydrated bicarbonate of ammonia*, and is composed, according to Phillips, of

2	proportionals of carbonic acid	22 × 2	= 44
1	,, ammonia		= 17
2	,, water	9 × 2	= 18
			79

This salt is less soluble than the carbonate, one part requiring eight of cold water for solution. It may be crystallized by cooling its hot solution, which must be made in a close vessel: its hot solution exposed to air loses carbonic acid, and reverts to the state of carbonate.

Omitting the water, therefore, it appears that there are three compounds of carbonic acid and ammonia. The *carbonate* composed of 1 proportional acid + 1 base; the *sesquicarbonate* composed of 1.5 acid + 1 base; and the *bicarbonate* of 2 acid + 1 base.

Oxalic Acid.—This acid may be regarded as a compound of oxygen and carbon, intermediate between carbonic oxide and carbonic acid, for it consists of

2	proportionals of carbon	(6 × 2)	= 12
3	,, oxygen	(8 × 3)	= 24
	Equivalent of oxalic acid		= 36

It may also be considered as composed of

1	proportional of carbonic oxide	= 14
1	,, carbonic acid	= 22
		36

These elements, however, cannot exist in these proportions independent of water or of a base; and the oxalic acid, in its usual crystalline form, contains half its weight of water. It appears, therefore, to consist of

1 proportional of anhydrous acid . . = 36
4 „ water . . (9×4) = 36

Equivalent of crystallized oxalic acid . = 72

When attempts are made to deprive it of water by heat, a portion only, amounting to about 20 per cent., can be expelled without the decomposition of the acid itself: some bodies, having a strong attraction for water, resolve it into its elementary gases. Dobereiner found this the case with anhydrous sulphuric acid (*Ann. de Chim. et Phys.*, xix.); and when the binoxalate of potassa is distilled with five or six times its weight of common sulphuric acid, equal measures of carbonic oxide and carbonic acid are evolved.

The history of the oxalic acid is so intimately connected with that of the vegetable acids, and its sources are so exclusively in the organic creation, that the general history of its formation and properties will be reserved for a future Chapter.

Carbon and Chlorine.—Mr. Faraday has ascertained that, by exposing carburetted hydrogen, mixed with great excess of chlorine, to the action of light, a white crystalline substance is formed, which, when purified by washing with water, is a *perchloride of carbon.* It is formed as follows: A glass vessel, capable of holding about 200 cubic inches, is properly mounted, with a stop-cock, and exhausted upon the air-pump: it is then nearly filled with chlorine, and afterwards placed in connexion with a jar of olefiant gas standing over water, and as much as can enter having passed in, the cocks are shut, and the whole left for a short time: when the fluid compound of chlorine and carburetted hydrogen has formed, the cocks are re-opened, and a fresh portion of carburetted hydrogen rushes in in consequence of the condensation which has taken place; this is left, as before, to combine with the remaining chlorine, and the process continued until no further action ensues, and the vessel is, in fact, full of carburetted hydrogen: chlorine is then similarly admitted, in repeated portions, and, ultimately, a quantity of the liquid hydrochloride of carbon is obtained, with an atmosphere of chlorine above it: in this state it is exposed to the direct rays of the sun. The chlorine speedily disappears, and muriatic acid is formed: this is absorbed by the admission of a little water; another atmosphere of chlorine is then admitted, and exposure to the sun repeated; by continuing these operations, crystals are at length formed in the liquid; these are to be collected, washed, and pressed between bibulous papers, then introduced into a glass tube, and sublimed by a spirit-lamp; the pure substance, with water, will rise at first, but the last portions will be partially decomposed, muriatic acid will be liberated, and charcoal left. The sublimed portion is then to be dissolved in alcohol, and poured into a weak solution of potassa, by which the substance is thrown down, and the muriatic acid neutralized and separated; then wash the substance with repeated affusions of water, collect and dry it, first between folds of paper, and then in the exhausted receiver of the air-pump. If quite pure, it sublimes without any change; and a small portion dissolved in ether gives no precipitate with nitrate of silver.

Perchloride of carbon thus purified is nearly tasteless; its odour resembles camphor; its specific gravity is about 2; it is a non-conductor of electricity, and powerfully refracts light. It is volatile, and in close vessels fuses at 320°; it boils at 360°, and may be distilled without decomposition: its vapour again condenses in crystals as it cools. It is not very combustible, but burns when held in the flame of a spirit-lamp, with the emission of much smoke and acid fumes. It burns vividly in oxygen gas. It is insoluble in water, but readily soluble in alcohol and ether; these solutions deposit arborescent and quadrangular crystals. It also dissolves in volatile and fixed oils. It is scarcely acted upon by alkaline and acid solutions; but most of the metals decompose this substance at a red heat. Potassium burns brilliantly in its vapour, causing the deposition of carbon, and the production of chloride of potassium. The metallic oxides also decompose it at high temperatures, producing metallic chlorides, and carbonic acid or oxide, according to the proportion of oxygen present; no water is produced, showing the absence of hydrogen in the compound. It appears, from various analytical experiments upon this compound, among which may be mentioned its decomposition, by passing it through red-hot peroxide of copper, that 100 parts afford 10 carbon + 90 chlorine; whence it would appear to consist of

2 proportionals of carbon	. .	6 × 2	= 12
3 „ chlorine	.	36 × 3	= 108
			120

When the above perchloride of carbon is passed through a red-hot tube containing fragments of rock-crystal to increase the heated surface, it gives off a portion of chlorine, and is converted into a liquid *protochloride of carbon*. It is a limpid colourless fluid, specific gravity 1.55, and not combustible, except retained in the flame of the spirit-lamp, when it burns with a yellow flame, much smoke, and fumes of muriatic acid. It does not congeal at 0°; it rises in vapour at about 165°. It is insoluble in water, but soluble in alcohol, ether, and the oils. It is not affected by the acids or alkalis, nor, at common temperatures, by solutions of silver. It dissolves chlorine, iodine, sulphur, and phosphorus. It affords, when decomposed, 17 carbon + 83 chlorine; whence it may be inferred to consist of

1 proportional of carbon	. . .	= 6
1 „ chlorine	. . .	= 36
		42

Subchloride of Carbon.—This compound was accidentally obtained in Sweden, whence it was brought by M. Julin, and submitted to analysis by Messrs. Phillips and Faraday. (*Ann. of Phil. N. S.* i. 216, and ii. 150.) It is a solid crystalline body, volatile by heat, without decomposition, and condensing into crystals. It is insoluble in water, but soluble in alcohol, ether, and essential oils. It sinks in water; it burns with a red flame, giving off much smoke, and fumes of muriatic acid. Acids do not act on it. When its vapour is highly heated in a tube, chlorine is given off, and charcoal deposited. Potassium burnt with it forms chloride of potassium, and liberates charcoal. Its vapour, detonated over mercury, with oxygen, formed carbonic acid and chloride of mercury: passed over hot oxide of copper, it formed a chloride of copper and carbonic acid; and over hot lime, it occasioned ignition, and produced chloride of calcium and carbonic acid. The relative proportions of its components appear to be

2 proportionals of carbon (6 × 2) . .	= 12
1 proportional of chlorine . . .	= 36
	48

This compound was formed during the distillation of protosulphate of iron and nitre; (both salts no doubt impure). All attempts at producing it by other means have failed; nor has it been converted into either of the other chlorides. (*Phil. Trans.* 1821, p. 392.)

Carbon and Iodine—Iodide of Carbon.—This compound was first obtained by Serullas, and considered as a hydriodide of carbon. (*Ann. de Chim. et Phys.* xx. 163, and xxii. 172.) It was subsequently examined by Mitscherlich. It is produced in the form of a yellow precipitate, when a saturated solution of iodine in alcohol is mixed with a strong alcoholic solution of potassa or soda: part of the iodine combines with the potassium or sodium, and the liberated oxygen unites to the hydrogen of the alcohol to form water, whilst another part of the iodine combines with the carbon of the alcohol. Iodide of carbon is of a lemon-yellow colour, and a sweetish taste. It crystallizes in brilliant spangles; its smell somewhat resembles that of saffron; its specific gravity is nearly 2. It is not sensibly soluble in water, but dissolves in 80 times its weight of alcohol of 0.825 specific gravity at 60°, and in 25 times at 95°. One part dissolves in 7 of ether. It also dissolves in fat and volatile oils; and when its solution in oil of lemon-peel is exposed to light, it is decomposed, and charcoal and iodine are deposited. Sulphuric, sulphurous, nitric, and muriatic acids have no action upon it, nor has aqueous solution of chlorine; but gaseous chlorine decomposes it, and forms chloride of iodine, and a white substance, which is probably a chloride of carbon. At common temperatures it gradually evaporates when exposed to air, and at 212° volatilizes without decomposition; between 240° and 248° it enters into fusion, and is soon decomposed, giving rise to vapours of iodine and a brilliant charcoal. If moisture be present, carbonic and hydriodic acids may be formed. (*Ann. de Chim. et Phys.* xxxvii. 85.)

When this solid iodide is mixed and distilled with perchloride of mercury, a liquid passes over, which is also an iodide of carbon, consisting, it is said, of

1 proportional of iodine . . . . = 125
1 ” carbon . . . . = 6
Equivalent of protiodide of carbon . = 131

The solid compound contains

3 proportionals of iodine (125 × 3) . = 375
2 ” carbon (6 × 2) . . = 12
Equivalent of periodide of carbon . = 387

It seems probable, that, if the above analysis be correct, three iodides of carbon will be found to exist: the above are the protiodide, and the sesqui-iodide; the true periodide, composed of two proportionals of iodine and one of carbon, remaining to be discovered. (*Ann. de Chim. et Phys.* xxxvii. 85.)

Carbon and Bromine—Bromide of Carbon.—This compound was also discovered by Serullas, and is formed by adding two parts of bromine to one of the solid iodide of carbon, and just enough solution of potassa to occasion the disappearance of the free iodine. A liquid bromide of carbon will appear at the bottom of the solution, which is to be separated by a funnel or otherwise, but without washing with water, and allowed to stand till it has become quite clear; during this time, crystals of iodate of potassa form upon the surface; the clear fluid beneath is to be withdrawn, and put into a weak solution of potassa, for the purpose of decomposing a little protiodide of carbon formed at the same time: a little bromide is also decomposed, but that which remains is soon left in a pure state. The principal properties of this (which is probably a *protobromide of carbon*), and the differences between it and the liquid protiodide, are as follows: the bromide becomes solid, hard, and crystalline at 32°, and remains solid up to 43°; the iodide remains fluid in the lowest temperatures. The bromide gives red vapour; the iodide violet vapour, when heated in the flame of a spirit-lamp. Neither of them act upon water, but are slowly decomposed in weak alkaline solutions. (*Ann. de Chim. et Phys.* xxxix. 225.)

Fluoride of Carbon is unknown.

Carbon and Hydrogen—Carburetted Hydrogen—Olefiant

Gas—Hydroguret of Carbon.—Carbon and hydrogen combine and form *carburetted hydrogen gas*, consisting of 1 proportional of carbon + 1 of hydrogen.

It is usually obtained by the decomposition of alcohol by sulphuric acid. For this purpose four parts of the acid and one of alcohol are put into a retort, and heated by a lamp. Very complicated changes ensue, which will be more fully explained under the article Alcohol; and soon after the mixture boils, the gas is evolved. It may be collected over water, and should be well washed with lime-water; its specific gravity to hydrogen is as 14 to 1, and to common air as 0.972 to 1. 100 cubic inches weigh 29.652 grains.

This gas has little odour when quite pure; it is inflammable, burning with a bright yellowish-white flame. Water absorbs about one-eighth of its volume. It is absorbed by sulphuric acid, no carbon being separated, nor sulphurous nor carbonic acid formed. In the course of several days, 1 volume of sulphuric acid absorbs between 80 and 90 of olefiant gas, and a peculiar compound results, capable of forming distinct salts. Such compounds will be more particularly noticed under the articles Naphthaline, Oil of Wine, and Sulphovinic Acid. It is unrespirable, and extinguishes flame. One part by volume requires, for perfect combustion, three of oxygen, and two of carbonic acid are produced. When sulphur is heated in one volume of this gas, charcoal separates, and two volumes of sulphuretted hydrogen result. As hydrogen suffers no change of volume by combining with sulphur, it follows that carburetted hydrogen contains two volumes of hydrogen condensed into one; hence the quantity of oxygen required for its combustion.

This gas is also decomposed by heat alone, as, by passing and repassing it through a red-hot tube of earthenware or metal, it then deposits its carbon, and is expanded into twice its original volume of pure hydrogen *.

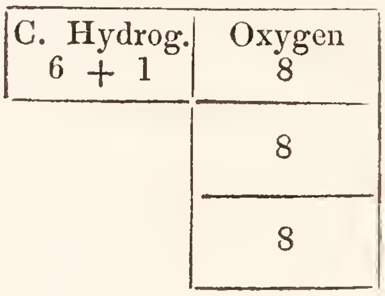
The following symbols show that one volume or proportional

---

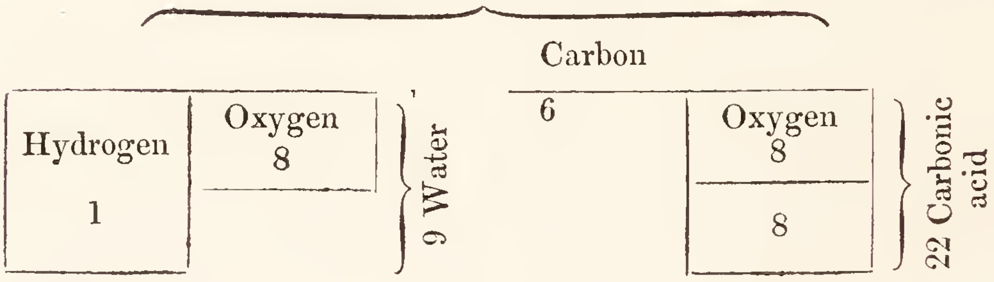
* When oil gas, compressed into vessels by a power equal to that of 30 atmospheres, is suddenly allowed to escape through a small aperture into the air, the expansion which it suffers appears to occasion in it a degree of chemical decomposition; for it deposits a black carbonaceous matter upon paper held in the current. (*Quarterly Journal, N. S.* i. 204.)

of this gas, mixed with three of oxygen, are converted into water and carbonic acid, the hydrogen being expanded to two volumes, or its real bulk.

After detonation.



Before detonation.



This gas, therefore, is constituted of carbon and hydrogen, bearing to each other the relative quantities of

1 proportional of carbon . . . . = 6
1 „ hydrogen . . . = 1
7

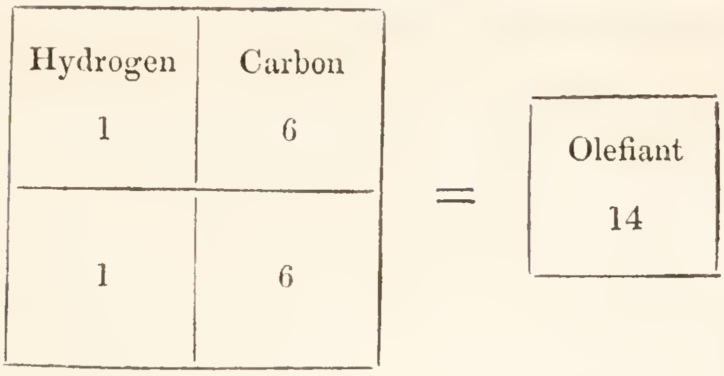
But it is also evident that 100 cubical inches contain

200 cubical inches of the vapour of carbon = 25.418 grains
200 „ hydrogen . . = 4.236 „
Weight of 100 cubic inches of olefiant gas = 29.654

These proportions are equivalent to

2 proportionals of carbon (6 × 2) . . = 12
2 „ hydrogen (1 × 2) . . = 2
Equivalent of olefiant gas . . . = 14

If, therefore, we take a volume of hydrogen and a volume of the vapour of carbon, they will only form half a volume of olefiant gas; hence it has been regarded as composed of 2 volumes of each of its components, and its equivalent, instead of 7, is considered as = 14, as shown in the following diagrams:—



No compound has yet been identified in which 1 volume of hydrogen and 1 of the vapour of carbon is condensed into 1 volume; such a compound would have the equivalent number = 7, which would also be its specific gravity to hydrogen.

Olefiant Gas and Chlorine.—When this gas is mixed with chlorine in the proportion of 1 to 2 by volume, the mixture, on inflammation, produces muriatic acid, and charcoal is abundantly deposited. If the gases be well mixed, and then inflamed in a tall and narrow glass jar (about 2 feet high and 4 inches in diameter), placed with its mouth upwards, the experiment is very striking; a deep red flame gradually descends through the mixture, and a dense black cloud of carbon rises into the atmosphere; fumes of muriatic acid are at the same time formed, and a peculiar aromatic odour is evolved. If, instead of inflaming the gases, the jar be inverted in a basin of water, or if they be mixed in a clean and dry glass globe exhausted of air, they act slowly upon each other, and a peculiar fluid is formed, which appears like a heavy oil; hence this compound has been termed *olefiant gas.*

Chloric Ether is the term applied to this fluid by Dr. Thomson, who, in 1810, ascertained that its component parts were chlorine and carburetted hydrogen. It has more lately been examined by MM. Robiquet and Colin (*Annales de Chim. et Phys.* vols. i. and ii.) The term *Hydrochloride of Carbon,* or *Hydrocarburet of Chlorine,* may properly be applied to it. It may be formed by allowing a current of each gas to meet in a proper receiver; there should be excess of olefiant gas, for if the chlorine be in excess, the liquid absorbs it. To purify it, it should be washed in water, and then carefully distilled from fused chloride of calcium. It is transparent and colourless; its taste sweet and somewhat acrid; its specific gravity = 1.2. It boils at 152°. It burns with a green flame, evolving muriatic acid, and largely depositing charcoal.

It is decomposed when passed through a red-hot tube. As it is produced by equal volumes of chlorine and carburetted hydrogen, it is probably a compound of one proportional of each gas, or of

Chlorine	36
Carbon	12
Hydrogen	2
	50

According to Gay Lussac, the specific gravity of its vapour is 3.44, and

			Grains.		Sp. Gr.
100 cubic inches of chlorine	=		76.250	..	2.50
100 „ olefiant gas	=		29.652	..	0.97
100 „ vapour of the hydrochloride	=		105.902	=	3.47

From Mr. Faraday's experiments, it appears that, by exposing this hydrochloride of carbon to the action of excess of chlorine, muriatic acid and chloride of carbon are the results. —See *Chloride of Carbon*, page 314.

Olefiant Gas and Iodine.—When iodine and olefiant gas are exposed to the action of light, they combine, and form a *hydriodide of carbon*, or *hydrocarburet of iodine.* This compound was first obtained in the Laboratory of the Royal Institution, by Mr. Faraday (*Phil. Trans.* 1821, p. 72.)

Iodine and olefiant gas were put, in various proportions, into retorts, and exposed to the sun's rays: after a while colourless crystals were formed, and a partial vacuum was produced: the gas in the vessels was found to contain no hydriodic acid. The compound was purified by introducing a solution of potassa into the retort, which dissolved the free iodine; the substance was then collected, washed, and dried.

The hydriodide of carbon is a white crystalline solid, volatile without decomposition, and in many respects analogous to the hydrochloride of carbon; its taste is sweet, and its odour aromatic. It sinks in sulphuric acid of the specific gravity 1.85. It is a non-conductor of electricity. When highly heated it evolves iodine: it is not readily combustible, but when held in the flame of a spirit-lamp, burns, diminishing the flame, giving off abundance of iodine and some fumes of hydriodic acid. It is insoluble in water, and in acid and alkaline solutions. It is soluble in alcohol and ether, and may be obtained in crystals from these solutions. The alcoholic solution is of a very sweet taste, but leaves a sharp sensation upon the tongue. Sulphuric acid does not dissolve it, but, when heated in the acid to between 300° and 400°, it is decomposed, apparently by the heat alone, and iodine and a gas (probably olefiant) are liberated. Boiling solution of potassa acts on it very slowly, but does gradually decompose it.

It was analysed as follows. Four grains were passed in vapour over heated copper in a green glass tube; iodide of copper was formed, and pure olefiant gas evolved, amounting to 1.37 cubic inches, or 0.413 grains. Now 4 grains, minus 0.413 grains, leaves 3.587 of iodine, and 3.587 : 0.413 :: 125 : 14.3 nearly—the constitution of this compound, therefore, is analogous to that of the hydrochloride of carbon;—it may be regarded as composed of

1 proportional of iodine	= 125
1 ,, olefiant gas	= 14
	139

Olefiant Gas and Bromine.—Hydrobromide of Carbon.—Hydrocarburet of Bromine.—When hydriodide of carbon is added to bromine, a hissing noise is produced, with much heat, and a bromide of iodine and fluid hydrobromide of carbon are formed. The bromide of iodine may be removed by water, and the hydrocarburet, with a slight excess of bromine, remains. It may be rendered colourless by a little alkali. If the hydriodide of carbon is in excess, but little of the hydrobromide is formed, but a subbromide of iodine.

The pure hydrobromide of carbon is colourless, heavier than water, of a penetrating etherial odour, a very sweet taste, and very volatile. It does not change colour by exposure to air. At 22° it becomes solid, and breaks like camphor.

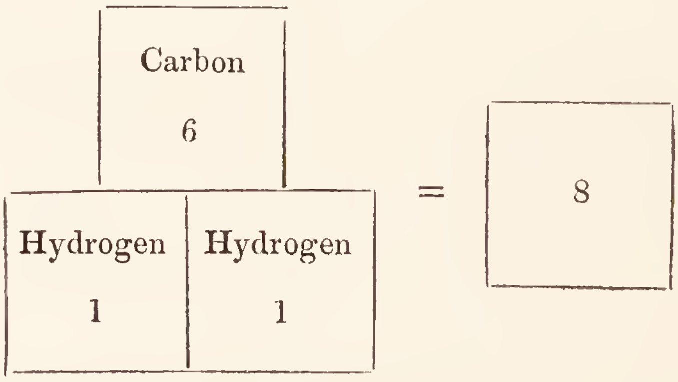
Bihydroguret of Carbon.—A gas, containing carbon and hydrogen, is often generated in stagnant ponds; and by passing the vapour of water over red-hot charcoal, or by distilling moist charcoal in an iron retort, at a red heat, and washing the gas thus afforded in lime-water, by which the carbonic acid is separated, a similar compound is said to be obtained

The specific gravity of these gases is liable to great variation, 100 cubical inches weighing from 12 to 20 grains. They burn with a paler flame, and require less oxygen than olefiant gas, for perfect combustion.

It has generally been stated that these gases contain a definite compound of carbon and hydrogen, to which the term *Light Hydrocarbonate* has been applied. From many experiments, however, on this subject, I am induced to consider them as mixtures of carburetted hydrogen, carbonic oxide, and hydrogen, since I have never been able to obtain any other definite compound of carbon and hydrogen, than olefiant gas; and since they may be imitated by mixtures of the above gases. The existence, however, of a true compound of two proportionals of hydrogen and one of carbon, appears proved by Sir H. Davy's experiments upon the fire-damp of coal-mines (*Phil. Trans.*, 1815), though I do not believe that such a gas can be produced artificially. He found 100 cubic inches to weigh 19.5 grains, but it was mixed with atmospheric air: if pure, 100 cubic inches should weigh 16.944 grains; its specific gravity to air being 0.555, and to hydrogen 8. It requires two volumes of oxygen for its perfect combustion, and the result is water and one volume of carbonic acid: it therefore consists of

1 proportional of carbon . . . . = 6
2 „ hydrogen . . . . . (1×2) = 2
Equivalent of the gas . . . . = 8

or of one volume of carbon vapour and two volumes of hydrogen, the three volumes being condensed into one of the gas, as follows:—



100 cubical inches of carbon vapour weigh . . 12.708 grains.
200 „ hydrogen 4.236
16.944

This gas is not decomposed with the same facility as olefiant gas ; but, in a very intense heat, it deposits carbon, and two volumes of hydrogen are liberated. Dry chlorine, even when aided by light, does not act upon it at common temperatures, but when the gases are moist and exposed to sunshine, a mutual action ensues : if there be excess of chlorine, carbonic and muriatic acid gases are produced. Passed with chlorine through a red-hot tube, or subjected to the electric spark, carbon is thrown down and muriatic acid formed.

Sir H. Davy made several experiments on the combustibility and explosive nature of this gas. He found that when 1 part of fire-damp was mixed with 1 of air, they burnt by the approach of a lighted taper, but did not explode ; 2 of air and 3 of air to 1 of gas produced similar results. When 4 of air and 1 of gas were exposed to a lighted candle, the mixture being in the quantity of 6 or 7 cubical inches in a narrow-necked bottle, a flame descended through the mixture, but there was no noise : 1 part of gas inflamed with 6 parts of air in a similar bottle, produced a slight whistling sound : 1 part of gas with 8 parts of air rather a louder sound : 1 part with 10, 11, 12, 13, and 14 parts, still inflamed, but the violence of combustion diminished. In 1 part of gas and 15 parts of air, the candle burnt, without explosion, with a greatly enlarged flame ; and the effect of enlarging the flame, but in a gradually diminishing ratio, was produced as far as 30 parts of air to 1 of gas.

The mixture which seemed to possess the greatest explosive power was that of 7 or 8 parts of air to 1 of gas ; but the report produced by 50 cubical inches of this mixture was less than that produced by one-tenth of the quantity of a mixture of 2 parts of atmospherical air and 1 of hydrogen.

In reference to the degree of heat required to explode this gas mixed with its proper proportion of air, it was found that a common electrical spark would not explode 5 parts of air and 1 of the hydrocarbonate, though it exploded 6 parts of air and 1 of the gas : but very strong sparks from the discharge of a Leyden jar seemed to have the same power of exploding different mixtures of the gas as the flame of the taper. Well-burned charcoal, ignited to the strongest red heat, did not explode any mixture of air and of the fire-damp ; and a fire made of well-burned charcoal, *i. e.* charcoal that burned without flame, was blown up to whiteness by an explosive mixture containing the fire-damp, without producing its inflammation. An iron rod at the highest degree of red heat, and at the common degree of white heat, did not inflame explosive mixtures of the fire-damp; but, when in brilliant combustion, it produced the effect.

The flame of gaseous oxide of carbon, as well as that of olefiant gas, exploded the mixtures of the fire-damp.

In respect of combustibility, then, this hydrocarbonate differs most materially from the other common inflammable gases. Sir Humphry found that olefiant gas, which explodes mixed in the same proportion with air, is fired by both charcoal and iron heated to redness. Carbonic oxide, which explodes when mixed with 2 parts of air, is likewise inflammable by red-hot iron and charcoal; and hydrogen, which explodes when mixed with three-sevenths of its volume of air, takes fire at the lowest visible heat of iron and charcoal; and the case is the same with sulphuretted hydrogen.

When 6 of air and 1 of the hydrocarbonate were exploded over water by a strong electrical spark, the explosion was not very strong, and, at the moment of the greatest expansion, the volume of the gas did not appear to be increased more than one-half*.

Nitrogen and carbonic acid mixed in different quantities with explosive mixtures of fire-damp diminished the velocity of the inflammation. Nitrogen, when mixed in the proportion of 1 to 6 of an explosive mixture, containing 12 of air and 1 of fire-damp, deprived it of its power of explosion; when 1 part of nitrogen was mixed with 7 of an explosive mixture, only a feeble blue flame slowly passed through the mixture.

One part of carbonic acid to 7 of an explosive mixture deprived it of the power of exploding; so that its effects are more remarkable than those of nitrogen, probably, in consequence of its greater capacity for heat, and probably, likewise, of a higher conducting power connected with its greater density.

These inquiries are very important, in reference to the exist-

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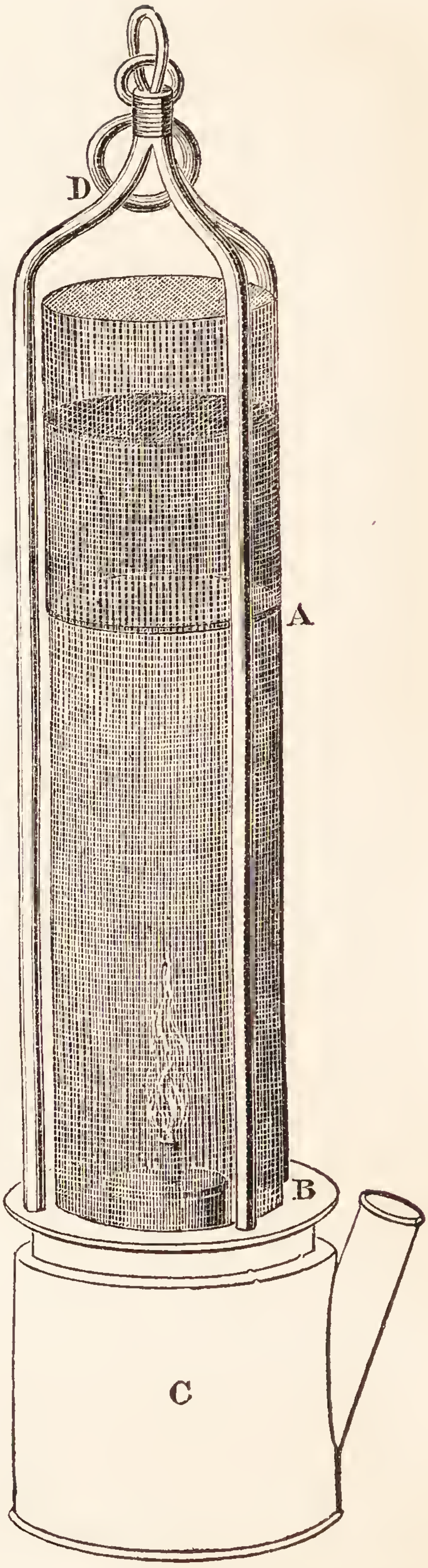
* This appears the expansion when the tube is very small; in larger tubes it is considerably more. The volume of the gas appears at least tripled during the explosion.

ence of this variety of hydrocarbonate, under the name of fire-damp, in coal mines. It is contained abundantly in certain coal strata, from fissures in which it is sometimes evolved in large quantities, forming what, in the language of the north-country miners, is called a *blower*. When this gas has accumulated in any part of the gallery or chamber of a mine, so as to be mixed in certain proportions, above referred to, with common air, the presence of a lighted candle, or lamp, causes it to explode, and to destroy, injure, or burn, whatever is exposed to its violence. The miners are either immediately killed by the explosion, and thrown, with the horses and machinery, through the shaft into the air, the mine becoming as it were an enormous piece of artillery from which they are projected; or they are gradually suffocated, and undergo a more painful death from the carbonic acid and nitrogen remaining in the mine, after the explosion of the *fire-damp;* or what, though it appears the mildest, is perhaps the most severe fate, they are burned or maimed, and often rendered incapable of labour and of healthy enjoyment for life.—Davy, *on the Safety-Lamp for Coal Miners;* London, 1818.

Sir H. Davy, in the treatise just quoted, has given a sketch of different, but ineffectual, contrivances of others, for the prevention of these dreadful, and hitherto frequently occurring accidents; and has described the train of investigation by which he was led to the discovery of a remedy at once simple and efficient, and which has already been submitted to repeated and successful trials.

The properties of flame, and the principle of safety adopted in this lamp, have already been adverted to (page 131). It is obvious, from what has there been said, that if the flame of a common lamp be everywhere properly surrounded with wire-gauze, and in that state immersed into an explosive gaseous mixture, it will be inadequate to its inflammation, that part only being burned which is *within* the cage, communication to the inflammable air *without* being prevented by the cooling power of the metallic tissue; so that by such a lamp the explosive mixture will be consumed, but cannot be exploded.

The wood-cut in the following page is a representation of the safety-lamp, as recommended for general use by Sir H. Davy: A is a cylinder of wire-gauze, with a double top, securely and carefully fastened, by doubling over, to the brass rim B, which screws on to the lamp C. The whole is protected and rendered convenient for carrying, by the frame and ring D. If the cylinder be of twilled wire-gauze, the wire should be at least of the thickness of one-fortieth of an inch, and of iron or copper, and 30 in the warp, and 16 or 18 in the weft. If of plain wire gauze, the wire should not be less than one-sixtieth of an inch in thickness, and from 28 to 30 both warp and woof.—Davy, *on the Safety-Lamp*, p. 114, *et seq*.



The operation of this lamp may be shown on a small scale by suspending it in a glass jar, and then admitting a sufficient stream of coal gas to render the inclosed atmosphere explosive; or, what answers nearly as well, by immersing it into a jar, at the bottom of which is some sulphuric ether, and which supplies by its vapour an inflammable atmosphere. The flame of the lamp first enlarges, and is then extinguished, the whole of the cage being filled with a lambent blue light; on turning off the supply of gas, or blowing out the etherial vapour, this appearance gradually ceases, and the wick becomes rekindled, when the atmosphere returns to its natural state.

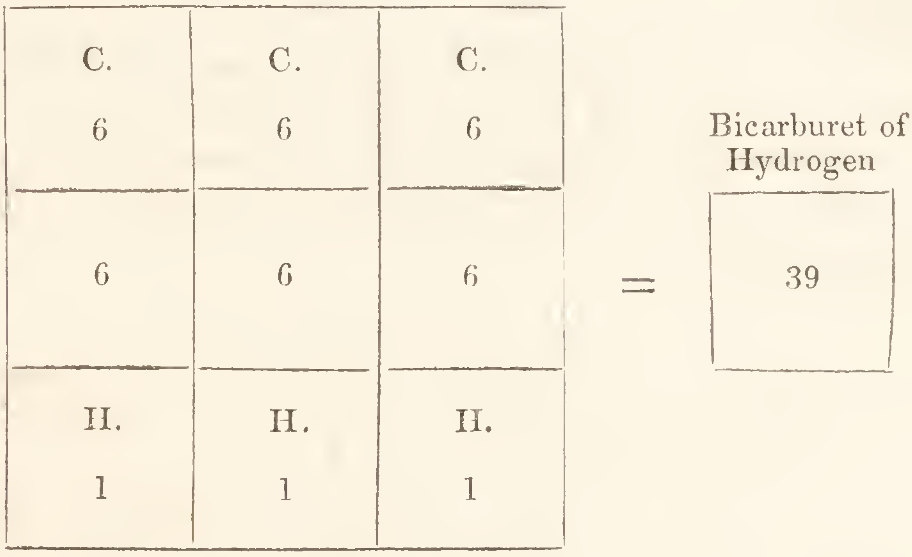
As the *safety* of these lamps entirely depends upon the perfect state of the wire-gauze, and upon the non-existence of any aperture or channel sufficiently large to admit of the passage of flame, they should, when in use in a coal mine, be inspected daily, to ensure their soundness in these respects. In gas manufactories, spirit warehouses, and in all cases where inflammable vapours or gases are likely to be generated, as in the examination of foul sewers and drains, it is obvious that these lamps are importantly applicable.

Bicarburet of Hydrogen.—For our knowledge of this and some other interesting combinations and properties of hydrocarbon, we are indebted to the analytic skill of Mr. Faraday. (*Phil. Trans.* 1825, page 440.) When certain oils are passed through red-hot tubes, as in the process for making gas, for the purpose of illumination, there is at the same time a vapour produced, which, by considerable pressure, and by cold, may be reduced to a liquid state. Large quantities of this liquid were obtained at the Portable Gas-works, where the gas obtained by the decomposition of whale oil is subjected in a large strong receiver to a pressure of 30 atmospheres; this occasions the deposition of the fluid, which is drawn of by a valve: it effervesces as it issues forth, and by the difference of refractive power, it may be seen that a dense transparent vapour is at the same time descending through the air from the aperture. This effervescence immediately ceases, and the liquid may be readily retained in ordinary stoppered or even corked bottles. 1000 cubical feet of good gas yield nearly one gallon of it. It appears as a thin light fluid, sometimes transparent and colourless, at others opalescent, being brown by transmitted, and green by reflected light; it has the odour of oil gas. Its specific gravity is 0.821: it does not congeal when cooled down to 0°; is insoluble in water, readily soluble in alcohol, ether, and oils; slowly decomposed by nitric acid, and forms peculiar combinations with sulphuric acid, afterwards to be noticed. This fluid Mr. Faraday found to be a mixture of various bodies, differing in their degrees of volatility: to separate them, he carefully distilled it into receivers, cooled to 0°, the receiver being changed with each rise of 10° in the retort, and the liquid retained in a state of incipient ebullition: it was thus found that the boiling point was most constant between 176° and 190°, at which temperature considerable quantities passed over without any change in the degree. Of this rectified fluid a portion was exposed to a temperature of 0°, when part of it solidified, and being collected and dried by pressure, did not liquefy till raised to 28°. Under common circumstances this portion appears as a colourless transparent liquid, having a peculiar odour like oil gas mixed with that of bitter almonds. Its specific gravity is 0.85 at 60°. When cooled to a little below 32°, it solidifies, and contracts considerably on congealing. It does not conduct electricity; evaporates when exposed to air, and boils at 186°. The specific gravity of its vapour at mean temperature and pressure is to that of hydrogen as 40 to 1; for 2.3 grains became 3.52 cubic inches of vapour at 212°. It is very slightly soluble in water, but readily soluble in alcohol and ether, and in oils. It burns with a bright flame and much smoke, and when put into oxygen, furnishes sufficient vapour to form a detonating mixture. Passed through a red-hot tube, it is resolved into carbon and carburetted hydrogen gas. Placed in the sunshine in chlorine, heat is evolved, muriatic acid formed, and a solid and liquid are produced, which appear to be compounds of chlorine, carbon, and hydrogen. Iodine does not act upon it, but dissolves in small quantity, forming a crimson solution. Potassium exerted no action upon it at a temperature of 186°. Neither alkalis nor their carbonates acted upon it. Nitric acid occasions in it little other change than the formation of a minute portion of hydrocyanic acid. Sulphuric acid added to it over mercury, exerted a moderate action; no heat was evolved, no blackening took place, no sulphurous acid was formed, but the acid became of a light yellow colour, and a portion of a clear colourless fluid floated, which appeared to be a product of the action, and which was not altered by water, and solidified at 34°, being then white and crystallized.

Mr. Faraday's attention was next directed to the composition of the substance: he decomposed it by passing its vapour over heated oxide of copper, by which it was resolved into carbonic acid and water, and a careful determination of their weights gave (as the mean of several experiments) 1 hydrogen and 11.576 carbon, as its components. Several other experiments led to the conclusion that this substance is a compound of

2 proportionals of carbon . .	(6 × 2)	= 12
1 proportional of hydrogen . . .		= 1
		13

It may, therefore, be regarded as a true *bicarburet of hydrogen;* and if we assume the specific gravity of its vapour compared with hydrogen as 39 to 1 (experiment giving 40), 100 cubical inches of its vapour will weigh at mean temperature and pressure 82.602 grains, and its specific gravity, compared with air, will be as 2.706 to 1; and in respect to the volumes of its components, it will consist of six volumes of the vapour of carbon and three volumes of hydrogen, condensed into the space of one volume; thus,



In examining the liquid remaining after the separation at 0° of the above crystalline solid, it was found to exhibit peculiarities which seem to identify it as a peculiar and definite compound; and from such experiments as were made upon it, it is extremely probable that it consists of one proportional of each of its components, but in what state of condensation has not been determined.

Quadri-hydrocarbonate.—It has already been stated, that a portion of the original oil-gas liquor is volatile at common temperatures; at the heat of the hand it passes off in vapour, and may be collected as a gas over mercury. It burns with a brilliant flame: its specific gravity to that of hydrogen is as 28 to 1; to that of common air as 1.943 to 1; and 100 cubic inches weigh 59.304 grains. It condenses into a liquid when cooled to 0, and inclosed in this state in a tube of known capacity, and hermetically sealed, the bulk of a given weight of it at common temperatures was ascertained: this, compared with water, gave its specific gravity as 0.627 at 54°; so that among solids or liquids it is the lightest body known. It scarcely dissolves in water, but readily in alcohol, and the solution effervesces from the escape of gas when water is added. It is abundantly condensed by sulphuric acid. One volume of the acid condenses above 100 volumes of the vapour, producing great heat, but no sulphurous acid. The solution is dark coloured, has a peculiar odour, and evolves no gas upon dilution. By detonation with oxygen, it was found that 1 volume of the vapour required 6 volumes of oxygen for perfect combustion, giving rise to 4 volumes of carbonic acid. The remaining 2 volumes of oxygen must have combined with 4 of hydrogen to form water. Upon which view, 4 volumes or proportionals of hydrogen = 4, are combined with 4 proportionals of carbon (6 × 4) = 24, to form 1 volume of the vapour, the specific gravity of which, compared with hydrogen, would be 28, which is also its equivalent number. This may be represented thus :—

C. 6	C. 6	C. 6	C. 6		Quadri-hydrocarbon.
H. 1	H. 1	H. 1	H. 1	=	28

As the relative proportions of the elements in this compound are the same as in olefiant gas, it became interesting to ascertain whether chlorine had the same action upon it. Chlorine and the vapour were therefore mixed in an exhausted retort, heat was evolved, and a liquid resembling hydro-chloride of carbon formed; but it could not be identified with it, inasmuch as it consisted of nearly equal volumes of the vapour and of chlorine; and, therefore, contained twice as much carbon and hydrogen. It was, therefore, treated with excess of chlorine in sunlight; muriatic acid was formed, and chlorine absorbed; a peculiar fluid was formed, consisting of hydrogen, chlorine, and carbon, but no chloride of carbon.

Mr. Faraday's researches, of which the above is an abstract, seem to have established a new and highly important and curious fact in chemistry, which is, that substances may exactly resemble each other in the relative proportions of their constituents, and yet, in consequence of peculiarities in their atomic arrangement, exhibit perfectly distinct physical and chemical properties. Thus, in the peculiar hydrocarbon just described, and in olefiant gas, the carbon and hydrogen are in the ratio of 6 to 1; but, in the former, the elements are united in the proportion of 24 to 4, and in the latter of 12 to 2. It has been observed by Dr. Turner, that this peculiarity is explicable on the supposition that the ultimate elements of such compounds are differently disposed. "It is to be presumed that the smallest possible particle of olefiant gas contains 2 atoms of carbon, and 2 of hydrogen; and that in like manner an integrant particle of the new compound of Mr. Faraday contains 4 atoms of each element. Neither of these substances could, I conceive, be formed by the direct union of a single atom of carbon and a single atom of hydrogen. If a combination of the kind were to occur, a new compound, different from any known at present, would be the result."

In respect to the nomenclature applicable in such cases there is obviously much difficulty. It has been proposed to designate the vapour by the term quadro-carburetted hydrogen; but such a term would rather indicate a compound of four proportionals of carbon with one of hydrogen. Till a less objectionable term, therefore, is proposed, I have called it *quadri-hydrocarbon;* and, upon the same principle, olefiant gas might be termed *bi-hydrocarbon.*

Naphtha and Naphthaline.—When *coal-tar* is distilled it furnishes various products, among which is a volatile liquor, which may be purified by redistillation, and this has a bituminous odour, is highly inflammable, and corresponds, in its general properties, to the native bitumen, known under the term *naphtha.* Potassium may be fused in it without losing its lustre; it therefore contains no oxygen; and when subjected to destructive distillation, or when its vapour is burned with oxygen, it is found to consist of carbon and hydrogen only. According to Dr. Thomson, it consists of six volumes of the vapour of carbon, and six of hydrogen, condensed into one volume of naphtha vapour (*First Principles*, i. 152). Among the other products obtained by the distillation of coal-tar, is a peculiar substance of a reddish or brown colour, and crystallizing in a beautiful manner in large translucent flakes. It has been called *Naphthaline.* By slow sublimation with a portion of powdered charcoal, it may be obtained colourless, and nearly inodorous. Its taste is slightly aromatic; it is heavier than water, unctuous to the touch, and slowly evaporates at common temperatures. It fuses at about 200°, and crystallizes as it cools; at 400° it boils and distils over, with little change. When inflamed, it throws off a singularly large quantity of black smoke, which diffuses itself in light films of carbon through the air. It is insoluble in cold, and very slightly soluble in boiling water; alcohol, ether, the oils, and naphtha, dissolve it abundantly.

The alkalis scarcely act upon it; nor does nitric or muriatic acid; but it combines with sulphuric acid, in which it readily dissolves by heat. According to Dr. Thomson, it is a sesqui-carburet of hydrogen, but its composition requires to be verified by further experiments.

The action of sulphuric acid on this substance has been ably investigated by Mr. Faraday (*Phil. Trans.* 1826). He found that, like other hydrocarbons, it combined with that acid, and produced a peculiar acid body, which he called *Sulpho-naphthalic acid.* He obtained it pure, by the following process: Naphthaline was fused with half its weight of sulphuric acid, which, on cooling, formed a red crystalline compound, soluble in water; carbonate of baryta was added to its solution, by which sulphate and sulpho-naphthalate of baryta were formed; the former insoluble, but the latter soluble: its solution was filtered off, and sulphuric acid added to it sufficient to precipitate the baryta. An aqueous solution of sulpho-naphthalic acid was thus obtained, of a bitter acid taste, and powerfully reddening litmus: concentrated by evaporation it became brown, thick, and, ultimately, solid and very deliquescent. By renewed heat it melted and charred, but did not flame, and ultimately gave sulphuric and sulphurous acid vapours, and left charcoal. Another portion of the acid was evaporated under an exhausted receiver, including a vessel of sulphuric acid. In some hours it became a white soft solid, apparently dry, and after a longer period was hard and brittle. In this state it was deliquescent in the air, but might be preserved unaltered in a close vessel. Its taste was bitter, acid, and metallic: when heated to 212° it melted, and crystallized and solidified as it cooled: more highly heated, water passed off, and it assumed a red tint, becoming probably anhydrous; further heated, it became brown and black, and naphthaline, sulphurous acid, and charcoal were evolved. This acid dissolves in water, alcohol, and oils. Its aqueous solution forms neutral salts with bases, all of which are soluble in water, most of them in alcohol, and all combustible, leaving sulphates or sulphurets, according to circumstances.

To determine the composition of this acid, and its equivalent number, its neutral salt with baryta was chiefly experimented upon; and the following appear to be the relative proportions of its elements:—

1	proportional of baryta		=	78
2	proportionals of sulphuric acid	(40 × 2)	=	80
20	„ carbon	(6 × 20)	=	120
8	„ hydrogen	(1 × 8)	=	8
Equivalent of the sulpho-naphthalate of baryta			=	286

Hence it appears, that the equivalent or proportional number of the acid is 208, and that it includes two proportionals of sulphuric acid, one of which is, as it were, saturated by the hydrocarbon; for it only combines with 78 of baryta, which will be found to be the equivalent of one proportional of that base.

This property of hydrocarbon, indicating its capability of uniting to an acid, saturating it, and performing, as it were, the part of a basis, has been more extensively inquired into and illustrated by Mr. Hennell: his experiments relate chiefly to certain combinations concerned and developed in the formation of ether, under which article the details will be given.

Caoutchouc. — I insert this substance among the hydrocarbons, inasmuch as it is almost the only natural compound of the kind. In examining the sap or fluid from which caoutchouc is obtained (*Quarterly Journal*, xxi. p. 19), Mr. Faraday found it to contain several substances; but the pure caoutchouc, which it deposits on standing, when thoroughly washed, was found to be a binary compound of carbon and hydrogen. Dr. Ure had previously arrived at the same conclusion, but the proportions of the elements are differently stated. It probably consists of

Carbon	6.812
Hydrogen	1.000

Coal and Oil Gas.—Mixtures of the hydrocarbons now described, and of some other gaseous compounds, are abundantly produced during the destructive distillation of coal and oil, and of a variety of other vegetable and animal substances; and the gases thus obtained are employed for the purposes of illumination, as economical substitutes for tallow, oil, &c. The destructive distillation of pitcoal is a process carried on upon a very extensive scale in several public and many private establishments. The coal is placed in oblong cast-iron cylinders, or *retorts*, which are ranged in furnaces, to keep them at a red heat, and all the volatile products are conveyed by a common tube into a *condensing vessel*, kept cold by immersion in water; and in which the water, tar, ammoniacal, and other condensible vapours, are retained; the gaseous products consist principally of varieties of carburetted hydrogen, with more or less sulphuretted hydrogen, and carbonic oxide, and acid: these are passed through or over hydrate of lime, or through a mixture of quicklime and water, in vessels called *purifiers*, by which the sulphuretted hydrogen and carbonic gases are absorbed, and the carburetted hydrogen gases transmitted sufficiently pure for use into *gasometers*, whence the pipes issue for the supply of streets, houses, &c. The coke remaining in the retorts is of a very good quality*.

The specific gravity of purified coal-gas is liable to much variation: sometimes it falls below 0.450, and at others exceeds 0.650. These differences are partly referable to the nature of the coal, but chiefly to the manner in which the process of distillation is conducted, as to duration and temperature: it has already been remarked, that when the varieties of hydrocarbon are passed through highly heated tubes, they are more or less perfectly decomposed into carbon and hydrogen: hence the gas which is obtained at a high temperature, or which, after its formation, has been in contact with red-hot surfaces, is apt to be partly decomposed; it is thus increased

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* Mr. Parker, of Liverpool (*Phil. Mag.* vol. iii. p. 292), has proposed to pass the gas as it comes from the coal retorts through red-hot iron tubes, by which the contaminating gases and vapours are further decomposed, and the quantity of useful gas much increased. This suggestion, if it succeeded, would greatly diminish the quantity of tar; but as carburetted hydrogen is decomposed at a red heat, it will obviously tend to diminish the illuminating power of the gas, though it will increase its quantity.

in bulk, but diminished in specific gravity, and in illuminating power; hence, too, analysis detects, in almost all coal gas, more or less uncombined hydrogen.

The best kind of coal for distillation is that which contains most bitumen and least sulphur. The chaldron should yield about 12,000 cubical feet of purified gas, of which each Argand's burner, equal to six wax candles, may be considered as consuming from four to five cubical feet per hour.

The economy of gas illumination may be judged of by examining the value of the products of distillation of a chaldron of coals, the average cost of which may be considered as 2*l.* It should afford—

		£	*s.*	*d.*
1¼	chaldron of coke, at 20*s.* . .	1	5	0
24	gallons of tar and ammoniacal liquor, at 1*d.*	0	2	0
12000	cubic feet of gas, at 13*s.* per 1000 C. F.	7	16	0
		£9	3	0

These products are taken nearly at their lowest value, but they afford ample grounds for showing the advantage of gas illumination, not merely for public purposes, but also in private establishments. It appears that where more than fifty lights are required, a coal-gas apparatus will be found profitable.

Messrs. J. and P. Taylor have constructed an apparatus for the conversion of oil into gas. It consists of a furnace with a contorted iron tube containing fragments of brick or coke, passing through it, into which, when red-hot, the oil is suffered to drop; it is decomposed, and converted almost entirely into charcoal, which is deposited in the tube, and into a mixture of carburetted hydrogen gases and vapours, of which from two to three cubic feet may be regarded as equivalent to five or six of coal-gas, for the production of light.—*Quarterly Journal*, vol. viii. The commonest whale-oil, or even pilchard-dregs, quite unfit for burning in the usual way, afford abundance of excellent gas, requiring no other purification than passing through a refrigerator, to free it of its more condensible vapours.

A gallon of whale-oil affords about 90 cubical feet of gas, of an average specific gravity of 0.900, and an Argand burner, equal to seven candles, consumes a cubical foot and a half per hour. If its specific gravity exceed 0.900, it may be considered as containing too large a proportion of the heavier hydrocarbons, by which the bulk of the produce is much diminished, which are apt to condense in the pipes and gasometer, and which also occasion a fuliginous deposit during the consumption of the gas in ordinary burners.

	s.	*d.*
The cost of a lamp, fed by oil or coal-gas, and giving the light of seven candles, will be	0	0¾ per hour.
Of Argand's lamp, with spermaceti oil .	0	3
Mould-candles	0	3½
Wax-candles	1	2

The following Table by Dr. Ure shows the relative intensities of light afforded by the combustion of different candles:

Number in a Pound.	Duration of a Candle.	Weight in Grains.	Consumption per Hour: Grains.	Proportion of Light.	Economy of Light.	Candles equal to 1 Argand.
10 mould . .	5 h. 9m.	682	132	12¼	68	5.7
10 dip . .	4 36	672	150	13	65½	5.25
8 mould . .	6 31	856	132	10½	59½	6.6
6 ditto . .	7 2½	1160	163	14⅔	66	5.
4 ditto . .	9 36	1787	186	20¼	80	3.5
Argand oil flame	. .	. .	512	69.4	100	

A pint of the best sperm oil, weighing about 13 ounces, burns, in a well-trimmed Argand, about 10 hours.

By a series of experiments, conducted with every requisite caution (*Phil. Trans.* 1820, p. 23), I found that, to produce the light of ten wax-candles for one hour, there were required

2600 cubical inches of pure carburetted hydrogen or olefiant gas.
4875 „ „ „ oil gas.
13120 „ „ „ coal gas.

The fitness of the gas obtained from coal for the purposes of illumination is, *cæteris paribus*, dependent upon the quantity of hydrocarbon which it contains; and, consequently, the fitness of the purified mixed gas for illumination will be directly as its specific gravity; or, the relative proportion of olefiant gas may be judged of by mixing the purified coal gas with twice its volume of chlorine over water, by which the olefiant gas will be absorbed, and its quantity shown by the amount of the absorption which takes place.

Experiments, thus conducted, show that purified *coal gas* seldom contains more than 40 per cent. in volume of olefiant gas, while *oil gas* generally affords about 75 per cent.; hence its superiority for burning, and the relatively small quantity consumed.

In consequence of the high and generally fluctuating price of oil, it became an important object to obtain a gas, of equal brilliancy and purity to that which it affords, from materials at once cheaper and less liable to fluctuations of value; and with this view, attempts were made to decompose rosin, in the apparatus above described. For this purpose melted rosin was substituted for the oil; but the exit pipes, by which the gas flowed off, soon became choked with a thick bituminous substance, which stopped the process; and the product of gas was small, and of inferior quality. Mr. Daniell has overcome the difficulty, by the invention of an apparatus, for which he has obtained a patent. The exit-pipe of the oil-gas apparatus rose from the upper part of the retort, and was purposely carried to a considerable height, that the volatile oil, which was condensed during the process, might flow back and add to the product of gas by its decomposition. It was the return of the volatile oil from rosin, which choked up the pipes when that substance was employed; and Mr. Daniell, observing this, led the exit-pipe from the *under* part of his retort into the hydraulic main, so that the return of any condensed vapour was rendered impossible. His mode of treating the rosin is to dissolve, with the assistance of a gentle heat, about 8lbs. in a gallon of the essential oil, which is plentifully formed during the decomposition of oil for making gas, or of rosin itself. This solution is allowed to trickle into the heated retort half filled with coke. A small diaphragm, just behind the exit-pipe, and filling half the diameter of the retort, prevents any of the liquid flowing into the hydraulic main. When the process is properly conducted, about 1000 to 1200 cubic feet of gas are obtained from the cwt. weight of rosin, and rather more than the original quantity of volatile oil is condensed, which is again employed for the solution. It is necessary to add a small quantity of lime to the essential oil, to neutralize a little acetic acid, which is formed during the process. The apparatus works perfectly free from all obstruction. The gas thus formed is equal in quality to oil-gas of 100 cubic feet to the gallon. Its average specific gravity is 0.850; it requires no purification; and its smell is rather resinous, and not nearly so offensive as that of either oil or coal-gas. Two cubic feet are equal in illuminating power to about five of the common coal-gas, and the expense of the material from which it is made, is not above one-third of the expense of oil. The sources of supply are as inexhaustible, and more generally distributed, than those of coal; and the forests of America, France, Spain, and Italy, yield the turpentine in quantities only limited by the demand. Many large towns in this country, in America, France, Holland, and the Netherlands, have already adopted the use of this gas, which will doubtless be introduced as an article of luxury, even in many places, where, from local circumstances, it may not be able to compete with coal-gas in cheapness. The elegance and simplicity of the manufacture, and the comparatively small capital required for the erection of the works, will also give it a preference in the creation of new establishments.

Dr. Henry's researches are the most important in reference to the philosophy of the art of gas illumination (Nicholson's *Journal*, 1805; *Phil. Trans.* 1808 and 1821); and much interesting matter connected with the subject will be found in an essay by Dr. Turner and Dr. Christeson (*Edinburgh Philosophical Journal*, 1825). The treatises of Mr. Accum and of Mr. Peckston contain an account of the apparatus, with details as to its construction and expense, together with much useful practical information.

The analysis of a mixture of hydrogen with olefiant gas, carbonic oxide, and carbonic acid, often requires to be performed in investigations relating to the gases used for illumination; it may be effected as follows:—

A hundred measures of the gas are introduced into a graduated tube, and the carbonic acid absorbed by a solution of potassa; the remaining gas is then transferred to thrice its volume of chlorine of known purity, standing over water in a tube of about half an inch diameter, and exposed to daylight, but carefully excluded from the direct solar rays; after 24 hours the carburetted hydrogen and the excess of chlorine will have been absorbed, especially after a little agitation, and the remaining gas, consisting of carbonic oxide and hydrogen, may be analyzed by detonation with oxygen in excess; the measure of carbonic acid formed being equal to that of the original carbonic oxide.

This proceeding depends upon the non-formation of chlorocarbonic acid in a mixture of carbonic oxide and chlorine in the contact of water, and out of the direct agency of the solar rays. Such mixture I have kept several days, occasionally renewing the chlorine as it became absorbed by the water, and have not observed any diminution in the bulk of the carbonic oxide. In all these cases it is necessary to ascertain the purity of the chlorine by its absorption by water, and to be aware of the evolution of common air from water during that process.

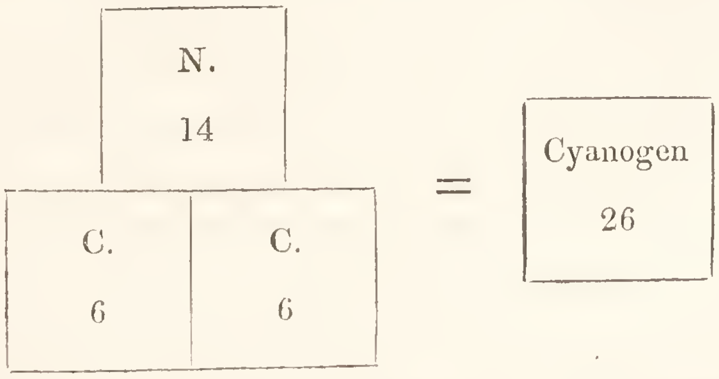
But in consequence of the presence of other compounds of carbon and hydrogen, and of those singular vapours discovered by Mr. Faraday, in coal, and especially in oil and resin gases, the accurate analysis of these complicated products becomes a problem of some difficulty. Dr. Henry's papers in the *Philosophical Transactions*, for the years 1808, 1820, and 1824, and in the *Annals of Philosophy* (vol. xv.) contain details upon the subject, which the student should carefully consult. The removal of the hydrocarburetted vapours from these gases may, as Mr. Faraday has shown (*Phil. Trans.* 1825, page 461), be accurately effected by the agency of sulphuric acid: this also absorbs olefiant gas, but much less rapidly than the vaporous compounds; and if the gas under examination be diluted with three or four times its bulk of common air or of hydrogen, and excluded from the sunshine, the absorption of olefiant gas by the acid will be prevented. The hydro-carburetted vapours may also be removed by subjecting the gas to the action of olive oil already saturated with olefiant gas.

As far as concerns the comparative value of different hydrocarburetted gases for the purpose of illumination, it seems evident, from Dr. Henry's experience, that, whatever be their source or composition, it may be most accurately determined by the quantity of oxygen required to saturate equal volumes. In other words, the illuminating powers of the different gases will be proportioned to the number of volumes of gaseous carbon condensed into one volume of the gas; and of these the oxygen consumed, and the carbonic acid produced, afford an accurate measure. (Henry's *Elements*, 1826, vol. i. 432.) "If 100 volumes, for instance, of one gas require for perfect combustion 100 volumes of oxygen, and 100 volumes of another gas take 200 of oxygen, the value of the second will be double that of the first. Specific gravity, though a guide to a certain extent, is not a sufficient one; for the weight of a gas may be owing to a large proportion of carbonic oxide, which only gives out a very small quantity of light. Photometrical experiments also appear to me to require greater perfection in the instruments that have been invented for that purpose, before we can implicitly trust to results obtained by their means: but there can be no fallacy in the combustion of these gases by oxygen, if conducted with ordinary care, and especially if in each instance an average be taken of two or three trials, which need not occupy more than a few minutes. Nor can it admit of doubt, that, other circumstances being equal, the brilliancy of light evolved by the combustion of gases which are constituted of purely inflammable matter, will bear a proportion to their densities, perhaps even a greater proportion than one strictly arithmetical; because, while, by the combustion of denser gases, a higher temperature is produced, the cooling agencies remain the same. It is probable, therefore, that of two gases composed of the same ingredients, that which has a double density will afford somewhat more than a double quantity of light."

Carbon and Nitrogen—Bicarburet of Nitrogen—Cyanogen—Prussine.—This gaseous compound was discovered in 1815, by Gay-Lussac (*Ann. de Chim.* xcv.) It may be obtained from dry and pure crystals of *cyanuret of mercury*. This substance when heated in a small glass tube to dull redness, becomes black, and a quantity of mercury passes over and condenses in the cold part of the tube: the gas which is at the same time evolved must be collected over mercury. Under a pressure of between three and four atmospheres at the temperature of 45°, Mr. Faraday condensed cyanogen into a limpid colourless liquid, of a specific gravity of about 0.9, and a refractive power rather less than that of water. When a tube containing it was opened, the expansion within appeared inconsiderable, and the liquid slowly evaporated, producing intense cold.

Cyanogen has a penetrating and very peculiar smell, somewhat resembling that of bitter almonds; it burns with a beautiful purple flame. Its specific gravity to hydrogen is as 26 to 1; 100 cubic inches weighing 55.068 grains; and to common air as 1.805 to 1. It sustains a high temperature without decomposition. Water dissolves 4.5 volumes, and alcohol 23 volumes of this gas. Sulphuric ether and oil of turpentine also absorb this gas. The aqueous solution reddens vegetable blues; and, according to Vauquelin (*Ann. de Chim.*, Oct. 1818), is subject to spontaneous decomposition, being gradually converted into carbonic and hydrocyanic acids, ammonia, a peculiar acid, which he calls the *cyanic*, and a brown substance containing carbon: the ammonia saturates the acids, and the carbonaceous compound is deposited. These changes are referable to the mutual re-action of the elements of cyanogen upon those of water.

Cyanogen may be analyzed by detonation with oxygen. One volume, detonated over mercury with two of oxygen, produces two volumes of carbonic acid, and one of nitrogen. Whence it appears that cyanogen consists of 2 proportionals of carbon = 12, and 1 of nitrogen = 14; the nitrogen having suffered no change of bulk by uniting with the carbon: its equivalent number, therefore, will be 26. It may be said to consist of 2 volumes of gaseous carbon + 1 volume of nitrogen, the 3 being condensed into 1 volume, thus:—

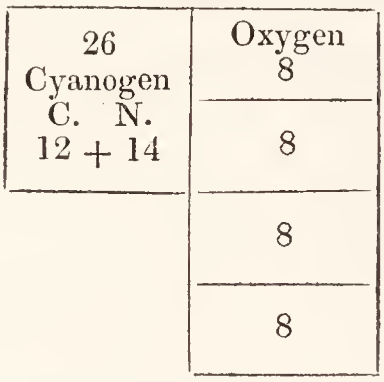


100	cubic inches of nitrogen weighing .	29.652 grains
200	,, vapour of carbon . .	25.416 ,,
100	,, cyanogen . .	= 55.068

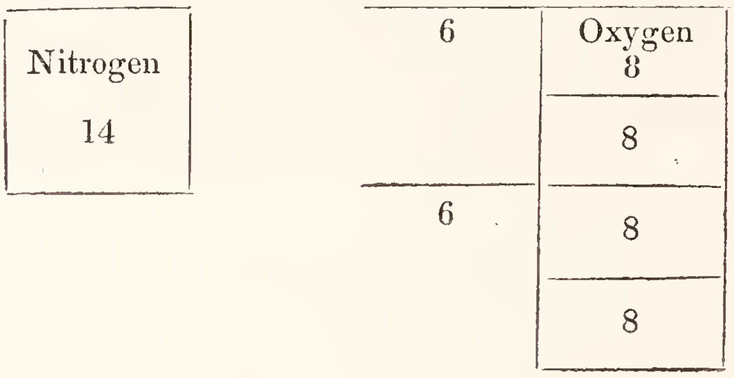
The following symbols exhibit the mixture of cyanogen with oxygen in the proportions above stated, and the result of their detonation.

Before detonation.

One proportional of Cyanogen and four of Oxygen.



After detonation.


One proportional of Nitrogen.

Two proportionals of Carbonic Acid.

Iodine, sulphur, and phosphorus may be sublimed in cyanogen without change; but when they are heated in contact with cyanuret of mercury, compounds of those bodies with cyanogen are the result. It also combines with several of the metals, and constitutes compounds which might be called *nitrocarburets*: they have sometimes been termed *cyanides*; but, perhaps, *cyanuret* is the least objectionable appellation.

Cyanogen and Oxygen—Cyanic Acid.—The existence of an acid, composed of cyanogen and oxygen, was first suspected by Vauquelin; but for the mode of obtaining it, its composition, and properties, we are indebted to Wöhler, and to Liebeg, though it can scarcely be said to have been hitherto procured in a detached state.

When cyanogen is passed into alkaline solutions it is absorbed, and, being acted on by the water present, is converted into cyanic and hydrocyanic acids, and salts of these acids with the alkaline base are formed, which, however, cannot be effectually separated. But, according to Wöhler, a true cyanate may easily be obtained by exposing a mixture of black oxide of manganese and ferrocyanate of potassa to a dull red heat, carefully avoiding too high a temperature, and boiling the resulting compound in spirit of wine of the specific gravity of 0.86. As the solution cools, tabular crystals of cyanate of potassa are deposited. When these are dissolved in cold water the solution slowly decomposes, and, if boiled, carbonic acid and ammonia are produced, in consequence of the re-action of the elements present. Cyanic acid forms a soluble salt with baryta, but it occasions insoluble precipitates in solutions of lead, mercury, and silver, and these cyanates may be decomposed by diffusing them through water, and exposing them to the action of a current of sulphuretted hydrogen, not in excess. A sour liquid, smelling like vinegar, is thus obtained, but it is very prone to decomposition.

According to the analysis of Wöhler (*Annales de Chimie et Phys.* xx. and xxvii.), corroborated by the experiments of Liebeg, cyanic acid consists of

1 proportional of cyanogen	26
1 „ oxygen	8
Equivalent of cyanic acid . . . . =	34

Under the articles *Mercury* and *Silver*, the process for preparing highly-detonating compounds of those metals, by acting upon their nitric solutions by alcohol, is stated: the experiments of Liebeg and Gay-Lussac (*Annales de Chimie et Phys.* xxiv. and xxv.) lead to the inference, that in these singular combinations the metallic oxides are united to an acid containing the same elements, and in the same proportions, as the cyanic acid, to which, in that particular state of combination, the term *Fulminic Acid* has been applied. The results of analysis confirm such an opinion, but the properties of the two acids appear in many respects distinct, and it has been suggested that the difference may arise from peculiarities in the atomic arrangement of the elements analogous to those of some of the hydrocarbons; the whole subject, however, is intricate, and requires further experimental elucidation, as will appear more evident by reference to the history of the above-mentioned fulminating compounds. One circumstance here deserves remark, which is, that nitrogen constitutes an element of all the powerfully-detonating combinations. It is singular that so inert a substance should be productive of such activity; it is possible that its unknown elements may be concerned in the compounds thus resulting, and that its evolution may arise from their re-union.

Cyanogen and Chlorine—Cyanuret of Chlorine—Chlorocyanic Acid—a compound first noticed by Berthollet, who termed it *Oxyprussic Acid.* M. Gay Lussac procured this compound by passing a current of chlorine through a solution of hydrocyanic acid in water, till the liquid discoloured a dilute solution of indigo in sulphuric acid. He then deprived it of excess of chlorine by agitation with mercury, and submitted it to careful distillation, by which an elastic fluid was evolved, consisting of a mixture of carbonic and chlorocyanic acids; and which, when condensed into water, furnishes a strong-smelling colourless solution, which reddens litmus. This compound neither detonates with oxygen nor hydrogen, but burns vividly with a mixture of the two. It is sour, and neither precipitates nitrate of silver nor baryta water. The alkalis absorb it, and when the compound is acted on by an acid, carbonic acid is evolved.

Serullas has given the following process for obtaining pure cyanuret of chlorine. Pure cyanuret of mercury, in powder, is moistened, and exposed out of the presence of light to the action of chlorine in a well-stopped phial: in the course of a few hours bichloride of mercury and chlorocyanic acid are formed. The bottle is then cooled to 0°, by which the chlorocyanic vapour is solidified: chloride of calcium is introduced, the stopper replaced, and the bottle moderately warmed, that all water may be absorbed by the chloride. The vapour is then resolidified by a second exposure to the freezing mixture, and in this state the bottle is filled with mercury, and a bent tube, properly attached, so that on applying to it a gentle heat, the cyanuret of chlorine may be collected in an elastic state over mercury. If the moist cyanuret of mercury in chlorine be exposed to light, carbonic acid, muriate of ammonia, and a peculiar liquid compound of chloride of carbon and chloride of nitrogen are generated: hence the necessity, in the above procedure, of carefully excluding water (*Ann. de Chim. et Phys.* xxxv. 291 and 337).

After an enumeration of the results of the mutual action of chlorine and cyanogen under various circumstances, M. Serullas details the properties of the cyanuret of chlorine.

At 0° it crystallizes in transparent needles. Between 6° and 12°, or under a pressure of four atmospheres at 60°, it is a limpid colourless liquid; and at temperatures above 12°, under ordinary pressure, it acquires the state of permanent vapour or gas, excessively irritating to the eyes and organs of respiration. Water at mean pressure and temperature dissolves about 25 volumes of it, alcohol 100 volumes, and ether about 50; but its solution does not redden litmus when pure, and it is expelled from water by heat without change. When free from cyanogen and from muriatic acid, it does not render turbid a solution of nitrate of silver.

It appears from the researches of Gay-Lussac, that chlorocyanic acid, in its pure and gaseous state, consists of 1 proportional of cyanogen + 1 proportional of chlorine, or 26 + 36 = 62. The gases by combination suffer no change of volume; hence the following symbols represent its composition and volume.—(*Annales de Chimie*, xcv. 205.)

Cyanogen	Chlorine		Chlorocyanic Acid
26	36	=	62

Its specific gravity, therefore, compared with hydrogen, is as 31 to 1, and to common air as 2.152 to 1—one hundred cubic inches weighing 65.65 grains.

Cyanogen and Iodine—Cyanuret of Iodine.—This compound was first obtained by Davy (*Quarterly Journal*, i. 289), and afterwards more fully examined by Serullas. It may be obtained by heating in a wide-mouthed vessel, a mixture of one part of iodine with two of pulverized cyanuret of mercury. Vapour of iodine first rises, but as soon as cyanogen is evolved white fumes are formed, which, if received into a paper cone, or cool glass receiver, condense in a flocculent form. If very slowly resublimed, it forms long acicular crystals of an acrid taste, pungent odour, and exciting a flow of tears. It is very poisonous. It is heavier than sulphuric acid. It dissolves in water, and still more readily in alcohol, and the solutions do not redden litmus: the alkaline solutions decompose it, forming hydriodates and hydrocyanates. It is instantly decomposed by solution of sulphurous acid; iodine is disengaged, and hydrocyanic evolved. Dry sulphurous acid gas does not act upon it. From the experiments of Serullas it is probably composed of

1 proportional of cyanogen . . . . = 26
1 „ iodine . . . . = 125

Equivalent of cyanuret of iodine . . . . = 151

Cyanogen and Bromine—Cyanuret of Bromine.—Two parts of dry cyanuret of mercury are put into a small tubulated retort, or into the bottom of a sealed tube plunged into a freezing mixture: one part of bromine is then added; a vivid action ensues, and so much heat is evolved, that if the temperature were not kept down the bromine would be volatilized: bromide of mercury and cyanuret of bromine are formed; the latter crystallizes in needles in the upper part of the tube, whence it may be sublimed into a cold receiver by the application of a gentle heat: sometimes it forms small cubic crystals. In many respects its physical properties resemble those of cyanuret of iodine; its odour is excessively pungent, and it is so volatile as to exist in vapour at temperatures above 60°. It is more soluble in water and alcohol than the compound of iodine. Solution of potassa transforms it into hydrocyanate and hydrobromate of potassa. The solution furnishes a precipitate when added to nitrate of silver, composed of cyanuret and bromide of silver, easily separable by ammonia, which dissolves the latter but not the former. Like the cyanuret of iodine, it is extremely deleterious to animals. One grain of it dissolved in a little water, and introduced into the œsophagus of a rabbit, occasioned instant death—as rapidly as hydrocyanic acid; it cannot, therefore, be examined without risk. Its composition has not been accurately determined (*Annales de Chimie et Phys.* xxxiv. 100).

Cyanogen and Hydrogen—Hydrocyanic or *Prussic Acid.* When a mixture of hydrogen and cyanogen is heated, or electric sparks passed through it, no mutual action is observed; this triple compound may, however, be obtained by the mutual action of cyanuret of mercury and muriatic acid, conducting the process as follows:—

Introduce the cyanuret into a tubulated glass retort, and pour upon it rather less than its weight of muriatic acid (sp. gr. 1.20). Adapt a horizontal tube to the beak of the retort, about two feet long and half an inch diameter; fill the first third of the tube next the retort with small pieces of white marble, and the other two-thirds with fragments of fused chloride of calcium; adapt to its extremity a small receiver, surrounded by a freezing mixture; on applying a gentle heat to the retort, hydrocyanic vapour will pass through the tube and become condensed in the cold receiver; any portion of muriatic acid and watery vapour that may rise along with it will be detained by the carbonate and chloride; after this part of the process the whole length of the tube should be gently heated to expel the residuary hydrocyanic acid. As the extrication of carbonic acid from the marble is not only inconvenient, but liable to carry off hydrocyanic acid, the distillation of any portion of muriatic acid should, as far as possible, be prevented, by placing the retort in an horizontal position, using the least possible quantity of it, and employing not more than a sufficient heat.

Another mode of obtaining hydrocyanic acid is that recommended by Vauquelin; it consists in placing cyanuret of mercury in a tube connected with a cooled receiver: sulphuretted hydrogen is then passed over the cyanuret, the sulphur of which combines with the mercury to form a sulphuret of mercury, and the hydrogen unites to the cyanogen to form hydrocyanic acid; the whole of which may be easily driven, by the application of a gentle heat, into the cold receiver, and there condensed. The aqueous solution of hydrocyanic acid is also obtained by passing sulphuretted hydrogen through water containing cyanuret of mercury in fine powder.

The hydrocyanic acid thus obtained has a strong pungent odour, very like that of bitter almonds; its taste is acrid, and it is highly poisonous, so that the utmost care should be taken to avoid the inhalation of its vapour. It volatilizes so rapidly as to freeze itself. It reddens litmus. The specific gravity of its vapour, compared with hydrogen, is 13.5 to 1, so that 100 cubic inches weigh 28.593 grains. It consists of 1 volume of cyanogen + 1 volume of hydrogen, forming two volumes of the hydrocyanic vapour.

Cyanogen	Hydrogen		Hydrocyanic Acid
26	1	=	27

These two volumes of hydrocyanic acid require for their perfect combustion two volumes and a half of oxygen—the results are water, two volumes of carbonic acid, and a volume of nitrogen. Gay-Lussac found that when potassium was heated in the gas, cyanuret of potassium was formed, and hydrogen, equal to half the volume of the acid, liberated. The ultimate components, therefore, of this acid are—

2	proportionals of	carbon	(6×2) =	12
1	„	nitrogen	=	14
1	„	hydrogen	=	1
				27

The specific gravity of the pure liquid acid at 60° is 0.7. It boils at 81°, and congeals at 3° into a congeries of acicular crystals.

The hydrocyanic acid dissolves in all proportions in water and alcohol. It is used in medicine as a sedative, and several formulæ have been given for its preparation: the following affords the acid of a convenient strength, and is that which is adopted at Apothecaries' Hall. One pound of cyanuret of mercury is put into a tubulated retort with six pints of water, and one pound of muriatic acid, sp. gr. 1.15; a capacious receiver is luted to the retort, and six pints are distilled over. If this first product contain any muriatic acid, it must be redistilled over a little carbonate of lime. The specific gravity of the product is 0.995. But, as Dr. Ure has remarked, the specific gravity of the acid is not an adequate test of its strength, which may be more satisfactorily determined as follows:—To 100 grains, or any other convenient quantity of the acid, contained in a small phial, add, in succession, small quantities of pure peroxide of mercury in very fine powder, till it ceases to be dissolved on agitation: the weight of the oxide taken up, being divided by 4, gives a quotient representing the quantity of real acid present. By weighing out beforehand, on a watch-glass, 40 or 50 grains of the peroxide, the residual weight of it shows at once the quantity expended (*Quarterly Journal*, xiii. 312). Dr. Ure's *Essay* also contains a table of the specific gravity of the acid of various degrees of dilution, and directions to ascertain the presence of muriatic acid in it. As this acid in its dilute state suffers partial decomposition by keeping, it should be prepared in small quantities only for pharmaceutical use, and preserved in vessels excluded from light.

The virulently poisonous nature of this acid has led to its occasional administration with criminal intentions: the mode in which it produces death and the symptoms are enumerated by medical and physiological writers, but the chemist may be called upon to suggest means of detecting it: this is generally easily effected in consequence of its very peculiar odour; and if the fluid containing it be agitated with finely-powdered peroxide of mercury, crystals of cyanuret of mercury may be obtained on evaporation. The following is a more accurate test of its presence, originally suggested by Scheele: to the suspected liquid add a solution of protosulphate of iron, and afterwards drop in pure potassa in slight excess, and after a short exposure to the air, redissolve the precipitate in muriatic acid. If hydrocyanic acid be present, the tint of Prussian blue will appear.

Except in cases of recent examination it is not easily detected in the contents of the stomach after death, since it is decomposed with their putrefaction. In such cases Leuret and Lassaigne have recommended the following procedure: The stomach and its contents, cut into pieces, are carefully distilled with water slightly acidulated by sulphuric acid: the volatile products are condensed in a receiver surrounded by ice, and examined by the above-mentioned method: in such cases the acid is also generally recognized by its odour.

Hydrocyanate of Ammonia.—This salt crystallizes in cubes or small prisms, and is extremely volatile. Dr. Thomson states, that when Prussian blue is exposed to a red heat, and the products of its decomposition received over mercury, that the glass receiver becomes coated with crystals of this salt. Like the other hydrocyanates it soon suffers spontaneous change, and it is decomposed by the carbonic and other feeble acids.

Cyanogen and Ammonia unite in the proportion of about 1 volume to 1.5, forming a compound which dissolves sparingly in water, giving a dark brown solution. It does not throw down Prussian blue from solutions of iron.

Sulphocyanic Acid.—It appears from the experiments of Mr. Porrett (*Phil. Trans.* 1814), and from those of M. Gay-Lussac (*Ann. de Chim.* xcv.), that cyanogen is capable of forming a compound with sulphuretted hydrogen. It may be obtained by mixing one volume of cyanogen with one and a half of sulphuretted hydrogen; they slowly combine, and form a yellow crystallized compound.

Mr. Porrett termed this compound *sulphuretted chyazic acid;* but the term *sulphocyanic acid* is now generally applied to it.

Sulphocyanic acid is most readily obtained by the following process, contrived by Vogel. Mix equal weights of flowers of sulphur and powdered ferrocyanate of potassa, and keep the mixture melted in a flask for half an hour; when cold, reduce the mass to powder, and digest it in water; filter the solution, and add a sufficiency of liquid potassa to throw down the iron held in solution. The liquid thus obtained is a solution of sulphocyanuret of potassium, from which liquid sulphocyanic acid may be obtained by distillation with phosphoric or sulphuric acid. Thus procured, it is of a pinkish hue, with an acetic odour, and is characterized by the peculiar blood-red colour which it produces when mixed with persulphate of iron. It reddens litmus, and neutralizes the alkalis, and forms a white insoluble salt with protoxide of copper. When concentrated, its specific gravity is 1.022. It boils at 217°, and at 15° it crystallizes. Most of its salts are soluble in alcohol. According to the experiments of Porrett and of Berzelius (*Annals of Philosophy*, xiii., and *Ann. de Chim. et Phys.* xvi.), sulphocyanic acid is composed of

1 proportional of cyanogen		= 26
2 proportionals of sulphur	(16 × 2)	= 32
1 proportional of hydrogen		= 1
Equivalent of sulphocyanic acid		= 59

or, of

1 proportional of bisulphuret of cyanogen	= 58
1 ,, ,, hydrogen	= 1
	59

The *Cyanuret of Sulphur* and the *Cyanuret of Phosphorus* have not, I believe, been examined, although they are probably formed when sulphur and phosphorus are heated with cyanuret of mercury.

Seleniocyanic Acid was obtained by Berzelius in combination with potassa, but he could not procure it in a separate state.

Carbon and Sulphur—Bisulphuret of Carbon.—This is a liquid obtained by passing the vapour of sulphur over red-hot charcoal in a porcelain tube; or by distilling about six parts of yellow iron pyrites (bisulphuret of iron) with one of charcoal. The product should be conveyed by a glass tube into cold water. When purified by redistillation, at a low temperature, with chloride of calcium, it is transparent, colourless, and insoluble in water, but soluble in alcohol and ether; its refractive power in regard to light is very considerable. Its specific gravity is 1.272. It boils at 106°, and does not freeze at — 60°. It is very volatile, and has a pungent taste and peculiar fetid odour. The cold which it produces during evaporation is so intense, that by exposing a thermometer bulb, covered with fine lint, and moistened with it, in the receiver of an air-pump, the temperature sunk, after exhaustion, to — 80°. When a mercurial thermometer was used, the metal froze.

Sulphuret of carbon is inflammable, and, when burned with oxygen, produces sulphurous and carbonic acids. It is decomposed by copper and by iron at a red heat. It consists of 1 proportional of carbon and 2 of sulphur; $6 + 32 = 38$. (Berzelius and Marcet, *Phil. Trans.* 1813.) It was discovered by Lampadius, who called it *Alcohol of Sulphur.*—Crell's *Annals*, 1796, ii.

Sulphuret of carbon does not dissolve in water, but it incorporates with alcohol and ether, and with fixed and volatile oils, and dissolves camphor. It is decomposed, when water is present, by chlorine and iodine; and when potassium is heated in its vapour it burns and decomposes it. It dissolves sulphur and phosphorus. Passed over heated lime or baryta, it produces ignition, and carbonates of those bases, together with sulphurets of calcium and of barium.

A portion of carburet of sulphur appears to be frequently formed during the production of inflammable gas from coal, and to be retained in the state of vapour by the gas after its purification by lime; such gas gives a sulphurous smell when burned, although perfectly cleansed from sulphuretted hydrogen, so as not in the slightest degree to discolour carbonate of lead.—Brande, *Phil. Trans.* 1820, p. 19.

Carbo-sulphuric Acid—Hydroxanthic Acid.—It appears, from the experiments of M. Zeise, Professor of Chemistry at Copenhagen, that carbon and sulphur form a base acidifiable by hydrogen, which he has called *Xanthogene*, from the yellow colour of its compounds: the acid he terms *hydroxanthic acid.* When an alcoholic solution of pure potassa is mixed with bisulphuret of carbon, a compound is obtained, which, evaporated under the exhausted receiver of the air-pump over a surface of sulphuric acid, or exposed to a temperature of 32°, deposits acicular crystals, which become yellow by exposure to air, are very soluble, and from which, upon the addition of dilute muriatic or sulphuric acid, an oily-looking fluid, heavier than water, is separated, which is the *hydroxanthic acid.* Exposed to air it becomes covered with an opaque crust: it reddens litmus; tastes sour, astringent, and bitter; is inflammable; and at 212° is decomposed into bisulphuret of carbon and a peculiar inflammable gas.

The action of ammonia on the sulphuret of carbon is very peculiar, and several new compounds result; but upon these subjects the reader must consult the original sources of information, which scarcely admit of abridgment, and which, indeed, are not very perspicuous in their details. (*Ann. de Chim. et Phys.* xxi. and xxvi.; *Annals of Phil. N. S.* iv.; *Quarterly Journal*, xviii.)

Carbon and Phosphorus—Phosphuret of Carbon.—To obtain this compound, Dr. Thomson directs the following process (*System*, i. p. 276):—Allow phosphuret of lime to remain in water till it no longer evolves gas; then add to the liquid excess of muriatic acid, agitate for a few moments, and throw the whole upon a filter; phosphuret of carbon remains, which is to be washed and dried. This compound is a soft powder, of a yellowish colour, without taste or smell: exposed to air, it slowly imbibes moisture, and acquires an acid flavour. Exposed to a red heat, it burns, and gradually gives out its phosphorus, the charcoal being prevented burning by a coating of phosphoric acid. It consists of phosphorus 0.62 + carbon 0.38 (Thomson's *Annals*, viii. 157). These numbers closely correspond with

Phosphorus	1 proportional	. . . =	12
Carbon	1 ditto	. . . . =	6
			18

It would appear from the mode of obtaining this phosphuret, that it forms an ingredient in phosphuret of lime, as usually prepared; it also is obtained in the process for procuring phosphorus.

Selenium and Carbon—Carburet of Selenium—Seleniuret of Carbon.—Berzelius has announced the existence of this compound, but has not described its properties. (*Lehrbuch der Chemie*, Dresden, 1826.)

Section VII. Boron.

This substance is obtained by heating in a copper tube two parts of potassium, with one of boracic acid previously fused and powdered. In this experiment the boracic acid, which consists of boron and oxygen, is decomposed by the potassium. The fused matter is washed out of the tube with water, and the whole put upon a filter. The boron remains in the form of a brown insipid insoluble powder, unaltered by exposure to air at common temperatures, but when heated to 600° it burns with much brilliancy, especially in oxygen gas, and produces *boracic acid*. One part of charcoal or lampblack, intensely heated in a gun-barrel, with nine parts of borax, previously fused, and in fine powder, produces a disengagement of carbonic oxide, and a blackish mass results, which, after copious washings in boiling water, and once with muriatic acid, affords a greenish-black powder, having the characters of boron mixed with a little charcoal. The charcoal probably first reduces the soda, and the sodium decomposes the boracic acid; hence the produce of boron would probably be increased by adding to the borax half its weight of soda or potassa, and double the quantity of charcoal above mentioned. (Doebereiner, *Ann. de Chim. et Phys.* ii. 214.) Boron is a non-conductor of electricity. Its specific gravity exceeds 2.

Boracic acid is usually obtained by dissolving the salt called *borax* in hot water, and subsequently adding half its weight of sulphuric acid; as the solution cools, white scaly crystals appear, which, when washed with cold water, are nearly tasteless, and which consist of boracic acid combined with about 40 per cent. of water, and retaining a little sulphuric acid, which it loses by exposure to a strong red heat, and fuses into a transparent hard glass. Its specific gravity before fusion is 1.48; after fusion, about 1.8. At a white heat this acid slowly sublimes.

Boracic acid is very difficultly soluble in water; boiling water takes up about $\frac{1}{50}$ its weight; the solution reddens vegetable blues, but possesses the singular property of rendering the yellow of turmeric brown, in the manner of an alkali. (*Quarterly Journal*, xi. 403.) Its solution in spirit of wine burns with a green flame. This acid was first obtained by Homberg, in 1702, and was used in medicine, under the name of *Homberg's Sedative Salt.* Its nature was first shown by Davy, in 1807.

The experiments upon the composition of boracic acid are much at variance. Berzelius regards it as containing 1 boron + 3 oxygen; and Dr. Thomson as composed of 1 boron and 2 oxygen: this latter determination has been most generally adopted, and it represents the dry boracic acid as composed of

1 proportional of boron . . .		= 8
2 proportionals of oxygen .	(8 × 2)	= 16
Equivalent of boracic acid . . .		= 24

Boracic acid is partially decomposed by hydrogen at high temperatures, and by some of the metals.

Native Boracic Acid has been found in the Lipari islands, and also in the hot springs of Sasso, in the Florentine territory; hence the term *Sassolin* applied to it by some mineralogists.

The boracic acid forms, with ammonia, a *Borate of Ammo-*

nia, composed, according to Berzelius, (*Annals of Philosophy*, iii. 57,) of

37.95	Acid.
30.32	Ammonia.
31.73	Water.

This salt forms small polyhedral crystals, of an alkaline taste.

Chloride of Boron is obtained by passing dry chlorine over an incandescent mixture of charcoal and boracic acid; it is a gaseous body, which may be collected over mercury; colourless, heavier than air, fuming when exposed to air, and it resists a high temperature without decomposition.

Iodide and Bromide of Boron are unknown.

Fluoride of Boron—Fluoboric Gas.—In the hope of obtaining dry fluoric acid, Gay-Lussac and Thenard heated a mixture of vitrified boracic acid and fluoride of calcium: the result was not as they had anticipated, but a peculiar gaseous compound was obtained, to which they gave the name of *fluoboric acid*. Dr. John Davy obtained the same gas, not, however, perfectly pure, by heating in a glass retort, over a lamp, a mixture of one part of vitrified boracic acid, two parts of finely-powdered fluor spar (fluoride of calcium), and twelve parts of sulphuric acid. It is most probable that, in obtaining this gas, the oxygen of the boracic acid combines with the calcium of the fluor spar to form oxide of calcium or lime, and that the boron and fluorine unite to produce the gas. The composition of this gas, as far as concerns the relative weights of its components, is by no means ascertained; and, indeed, till the nature of fluorine has been more rigidly determined, difficulties upon this point must occur.

Fluoboric gas, according to Dr. Thomson, has a specific gravity $= 2.362$: it is colourless, of a pungent odour, highly deleterious to respiration, and extinguishes flame. It strongly reddens litmus; and when bubbles of it are allowed to escape into the air, they produce a remarkable dense and white fume, in consequence of their eager attraction for, and combination with aërial moisture. Water takes up 700 times its volume of the gas, increasing in volume and density, and forming a caustic and fuming solution, in which Berzelius found boracic and hydrofluoric acids in combination: it would seem, therefore, that fluoboric gas decomposes water, and that the hydrogen of the water unites to the fluorine to form hydrofluoric acid, and the oxygen to the boron, to form boracic acid. When the solution is concentrated, the hydrofluoric and boracic acids again decompose each other, and the original compound is reproduced.

Neither the gas nor the liquid acid act upon glass, but they speedily decompose almost all organic substances: a piece of paper introduced into the gas, standing in a tall jar over mercury, causes its rapid absorption, and becomes charred as if burned, in consequence of the abstraction of the elements of water. When potassium is heated in fluoboric gas, it burns, and a brown compound results, consisting of boron and fluoride of potassium: the latter may be dissolved in water, and pure boron remains.

Fluoborate of Ammonia.—Fluoboric acid and ammonia condense each other apparently in three proportions. If one measure of the acid gas be admitted, to one of ammonia, in a jar over mercury, complete condensation ensues, and a solid neutral compound results. One measure of the acid and two of ammonia form a liquid, which may be made to absorb an additional volume of ammonia, and the compound still remains liquid.

CHAPTER V.

OF THE METALS, AND THEIR COMBINATIONS.

The metals constitute a numerous and important class of simple substances; many of them were diligently examined by the older chemists, who have left us valuable information concerning them; many are of more recent discovery; and the existence of several others has been demonstrated within the last twenty years.

The metals are forty in number.

1. Gold.
2. Silver.
3. Copper.
4. Iron.
5. Mercury.
6. Tin.
7. Lead.
8. Zinc.
9. Bismuth.
10. Antimony.
11. Arsenic.
12. Cobalt.
13. Platinum.
14. Nickel.
15. Manganese.
16. Tungsten.
17. Tellurium.
18. Molybdenum.
19. Uranium.
20. Titanium.
21. Chromium.
22. Columbium.
23. Palladium.
24. Rhodium.
25. Iridium.
26. Osmium.
27. Cerium.
28. Potassium.
29. Sodium.
30. Lithium.
31. Barium.
32. Calcium.
33. Strontium.
34. Magnesium.
35. Silicium.
36. Alumium.
37. Yttrium.
38. Glucium.
39. Zirconium.
40. Cadmium.

Of these metals the first seven were known in very remote ages. The ancients designated them by the names of the planets, to which they were supposed to have some mysterious relation; and each was denoted by a particular symbol, representing both the metal and the planet.

Gold	was the	Sun, and	was thus	represented	☉
Silver	,,	Moon	,,	,,	☽
Mercury	,,	Mercury	,,	,,	☿
Copper	,,	Venus	,,	,,	♀
Iron	,,	Mars	,,	,,	♂
Tin	,,	Jupiter	,,	,,	♃
Lead	,,	Saturn	,,	,,	♄

Zinc was not known to the ancients, though they were probably acquainted with its ores, and with their property of forming brass when fused with copper. (Pliny, lib. xxxiv. cap. 2 and 10.) The word *Zinc* first occurs in the writings of Paracelsus, who died in 1541. Bismuth is mentioned in the *Bermannus* of Agricola, written about 1530. Antimony was first obtained in its pure state by Basil Valentine towards the end of the fifteenth century. The process is described in his *Currus Triumphalis Antimonii.* Arsenic and Cobalt were discovered by Brandt in 1733 (*Acta Upsal.* 1733 and 1742); their ores were known at a much earlier period. Platinum was first recognised as ‘a peculiar body in 1741, by Mr. Charles Wood, Assay-Master in Jamaica. (*Phil. Trans.* vol. xliv.) In 1751, the distinctive characters of Nickel were shown by Cronstedt (*Stockholm Transactions*), and Manganese was obtained by Gahn in 1774. (Bergman's *Opuscula*, vol. ii.) Tungsten was discovered by MM. Delhuyart, in 1781. (*Mémoires de Toulouse.*) Tellurium and Molybdenum by Muller and Hielm, in 1782. Uranium by Klaproth in 1789. Titanium by Mr. Gregor, in 1789. Chromium by Vauquelin, in 1797. (*Ann. de Chim.* vol. xxv.) In 1802, Mr. Hatchett discovered Columbium. (*Phil. Trans.*) Palladium and Rhodium were discovered by Dr. Wollaston; and Iridium and Osmium by Mr. Tennant, all in 1803. (*Phil. Trans.*) Cerium was announced in 1804, by MM. Hisinger and Berzelius. (Gehlen's *Journal*, ii.) Potassium and Sodium were discovered in 1807, by Sir H. Davy, whose experiments also led to the discovery of the metallic nature of the ten following bodies. Stromeyer, of Gottingen, discovered Cadmium in 1818.

Metals are chiefly found in the earth in veins which traverse the granitic, schistose, and limestone rocks; and they also occur, although rarely, in rounded and detached fragments and nodules, disseminated through certain alluvial strata. They seldom occur in an uncombined state, but almost always united to other substances, as in the four following classes:—

i. *Native metals* are those which occur pure or alloyed, and have but a feeble attraction for oxygen; such as platinum, gold, silver, mercury, and copper.

ii. *Metals combined with simple supporters of combustion.* The compounds belonging to this class are chiefly *native metallic oxides:* there are also some native *chlorides; iodides* and *bromides* are extremely rare; and there are few *fluorides.*

iii. *Metals combined with simple inflammables.* This class includes the *native metallic sulphurets,* a very numerous and important series of ores. The *seleniurets* are very rare. One *native carburet* only is known, that of iron. There are no native hydrurets, phosphurets, nor borurets.

iv. *Metals in combination with acids—Metallic Salts.*—Of these the most common are the native *carbonates, sulphates,* and *phosphates:* there are a few native *borates;* and a few species belong also to this class in which the oxide is united to a *metallic acid:* such as the *native arseniates, chromates, tungstates,* and *molybdates.*

The metals, as a class, are characterized by opacity, and a peculiar lustre. Their opacity is such that, when extended into the thinnest possible leaves, they transmit no light; silver leaf, only one one-hundred-thousandth of an inch in thickness, is perfectly opaque. Gold is, perhaps, the only exception which, when beaten out into leaves one two-hundred-thousandth of an inch in thickness, transmit green rays of light. Their lustre depends upon their great power of reflecting light, in consequence of their opacity. They are excellent conductors of heat and of electricity. (See pages 44 and 67.)

The polished metals are very imperfect radiators and receivers of heat (page 120); but they are excellent reflectors both of light and heat, and hence their peculiar fitness for the construction of burning mirrors. According to Mr. Leslie, the metals, as *reflectors of radiant heat,* may be arranged in the following order, the highest number implying the greatest reflective power:—

Brass	100
Silver	90
Tin	80
Iron	70
Lead	60

Whenever the polish of the metallic surface is impaired, its power of reflecting heat suffers a proportionate diminution, while its power of absorbing, and also of radiating heat, is proportionately increased. (See page 120.)

There is the greatest difference in the specific gravity of the different metals, the heaviest and lightest solids being included in the list.

The principal metals, arranged according to their specific gravities, stand as follow:—

1.	Platinum	21.00
2.	Gold	19.30
3.	Tungsten	17.50
4.	Mercury	13.50
5.	Palladium	11.50
6.	Lead	11.35
7.	Silver	10.50
8.	Bismuth	9.80
9.	Uranium	9.00
10.	Copper	8.90
11.	Arsenic	8.35
12.	Nickel	8.25
13.	Cobalt	8.00
14.	Iron	7.78
15.	Molybdenum	7.40
16.	Tin	7.30
17.	Zinc	7.00
18.	Manganese	6.85
19.	Antimony	6.70
20.	Tellurium	6.10
21.	Sodium	0.972
22.	Potassium	0.865

The specific gravity of solids and liquids is always expressed in numbers referring to water as = 1.

To ascertain the specific gravity of solids, we employ a delicate balance, so contrived as to admit of substances being attached to one of the scales by means of a horse-hair or a fine thread of silk. The absolute weight of the body thus suspended is then very carefully ascertained: it is next immersed in distilled water, of the temperature of 60°; and the beam being again brought to an equilibrium, we learn the weight lost by its immersion; or, in other words, we ascertain the weight of its bulk of pure water. We now divide the sum of its absolute weight by that of the weight which it lost in water, and the quotient is its *specific weight*, or gravity, compared with water of the temperature of 60°.

Suppose a substance, weighing 360 grains, to lose 60 by immersion in water, the specific gravity of that substance will be $= 6$; for $360 \div 60 = 6$.

For ascertaining the specific gravity of liquids, we generally employ a thin phial, holding 1000 grains of distilled water, at the temperature of 60°. If filled with any other liquid, and weighed, we learn its specific gravity; thus we should find that it would contain 13500 grains of mercury; 1850 grains of sulphuric acid; 1420 grains of nitric acid, &c., which numbers of course represent the specific gravities of those liquids.

A bottle, however, holding 1000 grains, is often inconveniently large, and a small and thin globular phial, with a piece of thermometer tube ground into it by way of stopper, will be found more useful: such a phial should not weigh more than from 50 to 60 grains, and may contain between 400 and 500 grains of water. To use it, it should be accurately counterbalanced in a delicate pair of scales, and then filled with distilled water, and the stopper thrust in, the capillary opening in which allows a little to ooze out, and prevents the likelihood of bursting the phial; it is then to be wiped clean and dry, and again carefully weighed, by which the quantity of water it contains is ascertained; the water being poured out, it is next filled with the liquid whose specific gravity is required, taking care that it is of the same temperature as the water; we then weigh as before, and divide the weight by the former weight of water; the product gives the specific gravity required. Thus, suppose the phial to contain 425 grains of water at the temperature of 45°, it will be found to hold 5737.5 grains of pure mercury of the same temperature; and $5737.5 \div 425 = 13.5$ the specific gravity of mercury. Or, supposing the liquid lighter than water, such as alcohol, of which we may assume the phial to contain 350.5; then $350.5 \div 425 = 0.824$ the specific gravity of the alcohol under trial.

Among the metals, some are *malleable*, others *brittle;* hence the ancient division into perfect and semi-metals.

Common gold leaf is not more than $\frac{1}{280000}$th of an inch in thickness, and five grains are sufficient to cover a surface of more than 270 square inches.

Malleability, or the capacity of being extended by the hammer, belongs to the following metals, in the order following:—

Gold.
Silver.
Copper.
Tin.
Cadmium.
Platinum.
Lead.
Zinc.
Iron.
Nickel.
Palladium.

Potassium, sodium, and frozen mercury, are also malleable.

The malleable metals are also *ductile;* that is, they admit of being drawn out into wires. A grain of gold may be drawn, it is said, into 500 feet of wire; and by enveloping it in silver, Dr. Wollaston found that it might be so extended, as that 700 feet weighed only one grain; in thickness, therefore, not exceeding $\frac{1}{30000}$th of an inch. The coating of silver was removed by dilute nitric acid. In the same way he has produced platinum wire of excessive tenuity. The metals are arranged according to ductility as follows:—

Gold.
Silver.
Platinum.
Iron.
Copper.
Zinc.
Tin.
Lead.
Nickel.
Palladium.

Different metallic wires are possessed of different degrees of *tenacity*, by which is meant the power of supporting a weight without breaking. According to the experiments of Guyton Morveau, the following are the weights capable of being sustained by wires $\frac{787}{1000}$ths of a line in diameter.—*Ann. de Chim.* lxxi.

	lbs. avoir. dec. parts.
A wire of iron supports	549.250
„ copper	302.278
„ platinum	274.320
„ silver	187.137
„ gold	150.753
„ zinc	109.540
„ tin	34.630
„ lead	27.621

The following metals are brittle :—

Antimony.
Arsenic.
Bismuth.
Cerium.
Chrome.
Cobalt.
Columbium.
Manganese.
Molybdenum.
Tellurium.
Tungsten.
Titanium.
Uranium.

None of the metals are very *hard*, and many so soft as to yield to the nail. In the following table some of the metals are arranged in the order of their hardness :—

Titanium.
Tungsten.
Palladium.
Manganese.
Iron.
Nickel.
Platinum.
Copper.
Silver.
Bismuth.
Gold.
Zinc.
Antimony.
Cobalt.
Tin.
Arsenic.
Lead.

Elasticity and sonorousness belong to the hardest metals only.

Such are the essential physical characters of the metals; they also resemble each other in many of their chemical properties, as the following general observations show:—

Action of Heat.—The metals are all susceptible of fusion by heat, but the temperatures at which they liquefy are extremely various. Mercury is fluid at all common temperatures, and requires to be cooled to — 39° before it congeals. Potassium melts at 150°, and sodium at 200° : arsenic at 360°; tin at 450°; lead at 600°; zinc at 700°; and antimony at 800°. Silver, gold, and copper require a bright cherry-red heat; iron, nickel, and cobalt, a white heat; manganese and palladium an intense white heat; molybdenum, uranium, tungsten, and chrome, are only very imperfectly agglutinated at the highest temperatures of our furnaces; and cerium, osmium, iridium, rhodium, platinum, and columbium, require the intense heat produced by an inflamed current of oxygen and hydrogen, or that of Voltaic electricity: and in respect to titanium it is doubtful whether it has ever been fused.

Arsenic volatilises before it fuses; but in general at higher temperatures than that required for their fusion, the metals are volatile, and may be distilled in close vessels. Mercury, arsenic, potassium, tellurium, and zinc, are volatile at a red heat. Gold and silver are converted into vapour when exposed to the intense heat of the focus of a burning lens; and several of the other metals boil and evaporate under similar circumstances. It is probable that this would happen to all of them, if raised to sufficiently high temperatures.

Action of Oxygen.—When the metals are exposed at ordinary temperatures to the action of oxygen, or of common air, which produces analogous, though less powerful effects, they are very differently affected. If the gas be perfectly dry, very few of them suffer any change, unless heated in it; they then lose their metallic characters, and form a very important series of compounds, the *metallic oxides* *.

A few of the metals resist the action of heat and air so completely, that they may be kept in fusion in an open crucible for many hours without undergoing change. This is the case with platinum and gold; hence they and a few others were

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* The opinions of the older chemists upon the changes which the metals suffer by exposure to heat and air will be found in the Prefatory History.

called *noble* metals: by passing a strong electric discharge through them, when drawn into very fine wire, they are reduced to the state of impalpable powder, which is by some regarded as an oxide; but the appearance ensues in hydrogen as well as in common air, and the oxides of those metals are reducible by heat alone: the appearance, therefore, is probably referable to minute mechanical division only.

Other metals readily absorb oxygen when exposed to a temperature approaching a red heat; as iron, mercury, nickel, &c.: others absorb it when in fusion, as lead, tin, antimony, &c.; others at lower, or even at common temperatures, as arsenic, manganese, sodium, potassium, &c.

That the metals have very different attractive powers in regard to oxygen is also shown by the circumstance of one metal being frequently oxidized at the expense of another: thus the oxide of mercury, heated with metallic iron, produces metallic mercury and oxide of iron; potassium, heated with oxide of manganese, becomes oxidized, and metallic manganese is obtained. Upon the same principle, solutions of metallic oxides in the acids may often be reduced to the metallic state by the immersion of other metals. Mercury thus decomposes nitrate of silver; copper decomposes nitrate of mercury; and iron decomposes nitrate of copper. In these cases of metallic precipitation, electricity becomes active the moment that the deposition commences; the precipitating metal being positive, and that which is precipitated negative. Very beautiful crystalline deposits may thus often be obtained, as where silver is precipitated by mercury and lead by zinc.

Some of the oxides are decomposed by mere exposure to heat, as those of gold, mercury, &c.; others require the joint action of heat, and some body having a high attraction for oxygen, such as charcoal. Thus when oxide of lead is heated with charcoal, carbonic acid gas is evolved, and metallic lead obtained. This important process is termed *reduction*, and is performed in various ways, as will appear by reference to the history of individual metals. The reduction of an oxide is also frequently effected by passing a current of dry hydrogen over it in a heated tube; in this case the oxygen is carried off in the form of water. Sometimes the reduction of an oxide is effected by the aid of another metal possessed of a very superior attraction for oxygen ; potassium is thus sometimes employed, and in some cases complicated attractions are directed to the process of reduction, as in the production of potassium when iron and hydrogen are used.

Electricity is a most powerful agent in the reduction of metallic oxides, and capable, under certain circumstances, of overcoming the most powerful attractions. In cases of electric decomposition of oxides, hydrogen must always be present at the negative pole, to which the metal is also attracted : hence the oxides must be dissolved in or diffused through water ; or, where the evolution of the metal is prevented by the presence of water sufficient for the solution, the oxide must be moistened to a greater or less extent, according to circumstances. In short, there is, I believe, no case of real electro-polar decomposition which is unattended by the evolution of hydrogen, and I have reason to believe that water itself, when electrified under such pressure as to prevent the evolution of gaseous matter, suffers the transmission of electricity without decomposition. The tubes in which I attempted this experiment were generally burst ; but in two instances I succeeded in continuing to evolve the component gases of water by electricity, in sealed tubes, till the pressure became so great as to put an end to the extrication of air-bubbles : after this, some small particles, accidentally contained in the water, were seen quickly vibrating between the positive and negative wires.

The oxidizement of a metal is an essential preliminary to the formation of its salts, or, in other words, to its combinations with acids ; and in this respect common chemical nomenclature is inaccurate. Thus we speak of sulphate of *copper*, nitrate of *zinc*, &c., meaning sulphate of *oxide* of copper, nitrate of *oxide* of zinc, &c. This ambiguity is prevented with respect to the alkalies and alkaline earths, the oxides of their bases being characterized by a distinct termination : thus phosphate of *soda* means phosphate of *oxide of sodium*, &c. ; a circumstance which induced Sir H. Davy to propose an analogous termination for all the oxides, appropriately applied to their common Latin names : *Cupra*, oxide of copper ; *Argenta*, oxide of silver, &c. ; but this plan, which he extended to other compounds, was never generally adopted.

Each metal has a certain definite quantity of oxygen with which it combines ; and where the same metal unites in more than one proportion with oxygen, in the second, third, and other compounds, it is a multiple of that in the first, consistent with the law of definite proportionals. Thus, 100 parts of mercury combine with 4 of oxygen to produce the *protoxide*, and with 8 to produce the *peroxide*. Copper also forms two oxides; in the one 12.5 of oxygen are united to 100 of metal, and in the other 25.

M. F. de Montizon has attempted to show (*Ann. de Ch. et Ph.*, vii. 7) that a relation subsists between the quantity of oxygen with which the metals combine, and their specific gravities; the oxygen being a multiple or submultiple of the density; and he has given a table comparing the results deduced from such a theory, with those obtained by analysis; his instances, however, are not sufficiently satisfactory to establish the conclusion.

Among the combinations of metals with oxygen, some are insoluble in water, or nearly so, and have neither taste nor smell; others are soluble and sour, constituting the *metallic acids;* others are soluble and alkaline, forming the *fixed alkalis* and *alkaline earths.* They are of all colours, and frequently the same metal united to different proportions of oxygen produces compounds differing in colour: thus we have the *black* and *red* oxide of mercury, the *green* and the *black* oxide of manganese, &c.

The different oxides of the same metal form distinct salts with the acids, and the quantity of acid required to neutralize the oxide bears a direct proportion to the oxygen which it contains. Thus, 208 parts of protoxide of mercury, containing 8 of oxygen, combine with 40 of sulphuric acid to form the *protosulphate of mercury;* and 216 parts of the peroxide of mercury require 80 of sulphuric acid to constitute the *persulphate of mercury*. This law was first developed by Gay-Lussac (*Mémoires d'Arcueil*, ii. 159). It sometimes happens that the same oxide unites with an acid in two proportions, forming two distinct salts, in which case the acid in the second is a multiple of that in the first. Thus, 48 parts of potassa unite to 22 and to 44 of carbonic acid, forming a *carbonate* and a *bicarbonate* of potassa. We thus have an *oxalate*, a *binoxalate*, and a *quadroxalate*, of potassa, &c.

*Action of Chlorine**.—All the metals appear susceptible of combining with chlorine, and of producing a class of compounds which may be termed *metallic chlorides.*

There are a few of the metals which resist the action of chlorine at common temperatures, but when heated they all combine with it; some slowly; others rapidly, and with intense ignition. Copper leaf, powdered antimony, arsenic, &c., burn when thrown into the gas: mercury and iron inflame when gently heated in it; silver, gold, and platinum quietly absorb it.

The attraction of chlorine for metals is, with very few exceptions, greater than that of oxygen; consequently, when a metallic oxide is heated in chlorine, oxygen is evolved, and a chloride formed. The insoluble chlorides are also formed by adding solution of chlorine, or of the soluble chlorides, or of muriatic acid, to the soluble metallic salts. Thus chloride of silver, which is insoluble, is thrown down from the soluble nitrate of silver by solution of chlorine, of muriatic acid, and of common salt.

The physical and chemical properties of the chlorides are extremely various. They are nearly of all colours. They

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* The compounds of chlorine, iodine, bromine, and fluorine, which we have here designated *chlorides, iodides,* &c., have been formed by Berzelius and some other writers into a distinct class, designated *haloide salts;* by others they are termed *salts of the hydracids,* as opposed to the *salts of the oxyacids;* but I have not thought the value of such distinctions sufficient to induce me to infringe upon the general order of arrangement adopted in this Manual. The difference, however, in the constitution and peculiarities of the hydracids and their salts must not be overlooked: these acids are marked by the absence of oxygen, and by the union of their elements in one proportion only; so that one volume of each of their components combine to produce two volumes of the respective hydracids. The question how far hydrogen is essential to the developement of acid properties has been elsewhere adverted to. It is also to be remarked, that certain compound bases perform, as it were, the part of simple substances in constituting acids, especially with hydrogen: this is the case with cyanogen, which thus forms hydrocyanic acid, and with sulpho-cyanogen, which forms sulpho-cyanic acid; and the action of the metals upon these acids corresponds in many instances to their action upon those with simple bases; potassium, for instance, when it acts upon one volume of hydrocyanic acid disengages half a volume of hydrogen, and combines with the cyanogen, to form what we have termed *cyanuret of potassium;* from sulphocyanic acid it also disengages hydrogen, and a *sulphocyanuret of potassium* is the result. The termination *uret* is here employed consistently with the nomenclature applied to the simple combustibles; but others pursuing the analogy to chlorine, &c., just mentioned, have called these compounds *cyanides, sulphocyanides,* &c.

are generally unchanged by heat; but some undergo decomposition. Some are soluble, others insoluble, in water. Some permanent; others deliquescent. Several of them decompose water, giving rise to the formation of muriatic acid, and an oxide; or in some cases to a muriate.

The metallic oxides occasionally combine with each other, forming definite compounds; instances of such combinations are common in the mineral kingdom: in this case one of the oxides appears to perform the part of an acid, and the other that of base. Many of the compounds of silica furnish illustrative instances. The salts of the proper metallic acids are also analogous compounds.

Some chemists are of opinion that all chlorides become muriates when dissolved in water, but with most of the soluble chlorides this cannot be admitted, and all evidence is in favour of their dissolving in water without decomposition.

The chlorides are fusible, and many of them crystallizable. Some are extremely volatile at common temperatures, and others fixed in high heats. A few exist at all ordinary temperatures, in the liquid state. They are generally decomposed at a red heat by hydrogen, which produces muriatic acid, and reduces the metal. Anhydrous sulphuric acid appears not to act upon them; but the common hydrated acid decomposes them, with few exceptions, evolving muriatic acid: the theory of these changes is elsewhere explained. Some of the metals rapidly decompose certain chlorides in consequence of their superior attraction: thus chloride of silver is decomposed by zinc, &c. All the soluble chlorides furnish a white precipitate in solution of nitrate of silver.

The same metal often forms more than one compound with chlorine, and these compounds are designated as the oxides. Thus we have the *protochloride* and *perchloride* of mercury, &c.

Many of the metals decompose muriatic acid, in which case hydrogen is evolved, and a metallic chloride produced; and when metallic oxides are heated in muriatic acid, they generally give rise to the formation of a chloride and water.

There are a few metallic oxides which, at low temperatures, absorb and retain chlorine, but they hold it by very feeble attraction. The chlorides of potassa and of lime will be described under those bodies. It has also been combined with the oxides of iron, zinc, and copper. (Grouvelle, *Ann. de Chim. et Phys.* xvii.) The secompounds are decomposed by the acids.

Action of Chloric Acid.—The compounds of the metallic oxides with chloric acid are decomposed by heat with the copious evolution of oxygen, and a chloride generally remains: some of these salts have been long known, others only recently investigated. The *oxychlorates* have been scarcely examined.

Action of Iodine.—Iodine aided by heat acts upon many of the metals, and produces *metallic iodides.* Some of these are soluble in water without decomposition; others decompose water and produce *hydriodates;* others are insoluble. The insoluble iodides may generally be formed by adding a solution of iodine or of hydriodic acid to the soluble metallic salts.

Iodine often combines in more than one proportion with metals, forming a *protiodide* and a *periodide.*

The iodides are decomposed by chlorine and bromine, and a few by oxygen; but in the greater number of instances iodine expels oxygen from its combinations with the metals: they are also decomposed by nitric and by sulphuric acid. According to Gay-Lussac, when the vapour of iodine is passed over hot lime, baryta, and strontia, it does not expel their oxygen, but unites with them as oxides. These compounds are not very permanent, and are decomposed at a temperature a little exceeding that required to form them.

Action of Iodic Acid.—The compounds of this acid with the metallic oxides have been but little examined: they are decomposed by heat, sometimes with the evolution of oxygen only; at others, iodine is also given off.

Action of Bromine.—Bromine combines with the metals and produces *bromides*, analogous, in their general habitudes, to the chlorides and iodides. Chlorine disengages bromine from its binary metallic compounds, and bromine expels iodine from the iodides; so that the attraction of bromine for the metals is intermediate between chlorine and iodine.

The *Bromates* are little known.

Action of Fluorine.—As fluorine has not been obtained in a separate state, its immediate action upon the metals is not known; but it would probably be energetic. Such of the *fluorides* as are insoluble may be obtained by the medium of a solution of fluoride of potassium, or by precipitation by hydrofluoric acid: the soluble fluorides are formed by digesting the oxides in the hydrofluoric acid. The fluorides are not decomposed by oxygen, chlorine, iodine, or bromine; but they are immediately recognized by the evolution of hydrofluoric acid, when moistened and heated with sulphuric acid, and by their action upon glass under such circumstances.

Action of Hydrogen.—Hydrogen forms permanent compounds with two of the metals only, namely, arsenic and tellurium. It appears to combine with each in two proportions, forming two solid compounds, the *hydrurets* or *hydrogurets* of arsenic and tellurium; and two gaseous compounds, *arseniuretted* and *telluretted hydrogen*. At high temperatures it dissolves potassium, forming *potassiuretted hydrogen gas*.

There are many of the metallic oxides and chlorides, which are decomposed by hydrogen: the oxides are reduced with the formation of water, and the chlorides with the production of muriatic acid.

Action of Water.—Those metals which are speedily acted upon by common air and oxygen, are also generally susceptible of decomposing water; some of them rapidly, others slowly. There are some metals which are not acted upon by air deprived of moisture, nor by water deprived of air; but moist air, or water containing air, effect their oxidizement: this appears to be the case with iron. (Dr. Marshall Hall, *Quarterly Journal*, vii. 55.)

Water combines with some of the metallic oxides, and produces *hydrated oxides*, or *metallic hydrates*. In these the relative proportion of water is definite. Some are easily decomposed by very moderate heat, as hydrate of copper; others retain water even when heated to redness, as hydrate of potassa; others are decomposed at a red heat, as hydrate of lime.

Action of Nitric Acid.—As no metal is soluble in an acid except in the state of oxide, and as the greater number of metals are capable of decomposing nitric acid, and of resolving it into some of the other nitric compounds, nitric acid is a very generally acting solvent of these bodies. It dissolves nearly all the metallic oxides and produces a numerous class of *nitrates*, which, if prepared with heat and with excess of acid, generally contain the metal at its maximum of oxidizement. The nitrates are all decomposed by a red heat; they give off oxygen and nitrogen, either separate or combined, and the metallic oxide remains. They are also decomposed when heated with sulphur, phosphorus, or charcoal; and sulphurous, phosphoric, and carbonic acids are formed: the phosphoric, being a fixed acid, remains united to the metallic oxide; while the sulphurous and carbonic acids are usually expelled. The nitrates are decomposed by sulphuric acid, nitric acid is evolved, and *sulphates* are formed.

In the neutral nitrates the proportion of oxygen in the acid is to that in the base as 5 to 1. Thus in the nitrate of potassa 48 parts of potassa, containing 8 of oxygen, are combined with 54 of nitric acid, containing 40 of oxygen; and in the pernitrate of copper, 80 parts of peroxide of copper containing 16 of oxygen, are combined with 108 of nitric acid, containing 80 of oxygen.

Action of Ammonia.—At high temperatures some of the metals are capable of decomposing ammonia. Liquid ammonia dissolves several of the metallic oxides, and with some of them forms crystallizable compounds. It dissolves the oxides of silver, copper, zinc, arsenic, antimony, and tellurium; the protoxides of iron, cobalt, and nickel; and the peroxides of tin, mercury, gold, and platinum. These ammoniated oxides, or *ammoniurets*, are all decomposed by heat. The compounds of ammonia with the oxides of gold, silver, and platinum, detonate when heated, and the oxide and the ammonia are both decomposed.

Action of Sulphur.—All the metals appear capable of forming *sulphurets*. These are in some cases formed by heating the metal with sulphur; in others, by decomposing the sulphates; and in others, by the action of sulphuretted hydrogen. The sulphurets are in general brittle; some have a metallic lustre; others are without lustre. They are fusible. Some are soluble, but the greater number insoluble in water. Where the same metal forms two sulphurets, the sulphur in those containing the largest proportion is an exact simple multiple of the sulphur in those containing the smallest proportion; hence we have *sulphurets* and *bisulphurets*. When the metallic sulphurets are heated, some undergo no change, as those of sodium and potassium; others sublime unaltered, as sulphuret of mercury and sulphuret of arsenic; others lose a portion of their sulphur, and, if air be admitted, sulphurous acid escapes, and the metal passes into the state of oxide, as sulphuret of lead: others again are entirely decomposed, the metal being completely reduced; this happens on heating sulphuret of platinum or of gold. It is doubtful whether any definite compounds of sulphur with the metallic oxides exist.

Hyposulphurous Acid combines with the metallic oxides, and produces a class of salts termed *hyposulphites*. Several of these have been examined by Mr. Herschel. (*Edinburgh Philosophical Journal*, i.) In some of their characters they resemble the sulphites: they are easily soluble; of a bitter or sweet taste; and decomposed by a heat below redness, and by almost all other acids. Their solutions readily dissolve chloride of silver.

Sulphurous Acid combines with many of the metallic oxides, producing *sulphites;* in some instances oxygen is transferred from the oxide to the acid, and sulphates result.

The *sulphites* are soluble in water, and have a sulphurous taste and smell. Exposed to moist air, they absorb oxygen, and pass into the state of sulphates. They are decomposed by sulphuric acid, which expels sulphurous acid, and the salts are converted into sulphates. When perfectly pure they are not affected by solution of baryta.

Hyposulphuric Acid forms with the metallic oxides a class of *hyposulphates*, which have been very imperfectly examined. They do not afford precipitates with solution of baryta.

Sulphuric Acid, in its concentrated state, is acted upon by a few of the metals only; when diluted, some of them are oxidized at the expense of the water, hydrogen is evolved, and the metallic oxide combines with the acid, producing a *sulphate*. In these cases the hydrogen evolved is the indicator of the quantity of oxygen transferred to the metal; every volume of hydrogen is the equivalent of half a volume of oxygen, and accordingly the production of 100 cubic inches of hydrogen indicates the transfer of 50 of oxygen, or, by weight, of about 17 grains. As different metals unite to different weights of oxygen, they will obviously evolve different quantities of hydrogen. Thus, if one metal, to become soluble in sulphuric acid, require to be united with 10, and another with 20 per cent. of oxygen, the latter will evolve twice the volume of hydrogen, compared with the former.

As the evolution of hydrogen, during the solution of a metal in dilute sulphuric acid, is referable to its oxidizement, no hydrogen will be evolved by the action of the acid upon an oxide, but it will be merely dissolved.

The sulphates are an important class of salts. The greater number of them are soluble in water, and the solutions are rendered turbid by solutions of baryta. The sulphates of potassa, soda, lithia, lime, baryta, and strontia, resist a white heat without decomposition: the other sulphates evolve, when intensely heated, sulphuric acid, sulphurous acid, and oxygen. Many of them are decomposed at high temperatures by the action of hydrogen, which carries off the oxygen of the acid, and of the base, and leaves a metallic sulphuret. In some cases the sulphur also combines with the hydrogen, and the sulphate thus affords a reduced metal. They are all decomposed at a red heat by charcoal, and most of them are thus converted into sulphurets; carbonic acid, and carbonic oxide, being at the same time evolved.

In the neutral sulphates the proportion of oxygen in the acid is to that in the base as 3 to 1. Thus sulphate of soda is composed of 32 soda, containing 8 of oxygen, combined with 40 of sulphuric acid, containing 24 of oxygen; and in the persulphate of copper, 80 parts of peroxide of copper, containing 16 of oxygen, are combined with 80 of sulphuric acid, containing 48 of oxygen.

Action of Sulphuretted Hydrogen.—It seems doubtful whether any of the metals combine with sulphuretted hydrogen. It unites with several of their oxides, and forms *hydrosulphuretted oxides.* A very few of these compounds are insoluble, and may be formed by adding a solution of sulphuretted hydrogen, or of hydrosulphuret of ammonia, to solutions of the respective metallic salts. Generally, however, a decomposition is effected in these cases, both of the sulphuretted hydrogen and of the oxide, and a metallic sulphuret is formed, the hydrogen combining with the oxygen of the oxide to form water, and the sulphur uniting to the metal. In a few cases the metallic oxide is reduced. The following Table shows the effect of sulphuretted hydrogen and of sulphuretted hydrosulphuret of ammonia upon solutions of several of the metals, as far as colour of the precipitate is concerned.

METAL.	*SOLUTION.*	*SULPHURETTED HYDROGEN.*	*HYDROSULPHURET OF AMMONIA.*
MANGANESE	Neutral protomuriate	No precipitate	Copious ochre yellow
IRON . .	Neutral protosulphate	Blackish and small in quantity	Black and abundant
Ditto . .	Permuriate	Abundant black	Black
ZINC . .	Muriate	A little opalescent and then milky	Straw colour and copious
TIN . .	Acid protomuriate	Brown	Deep orange
Ditto . .	Acid permuriate	At first 0, then yellow and copious	Apple green
CADMIUM .	Muriate	Yellow	Yellow
COPPER . .	Protumuriate	Deep brown	Brown
Ditto . .	Pernitrate	Black	Brown and black
LEAD . .	Muriate and nitrate	Black	Brown and black
ANTIMONY .	Tartrate of antimony and potassa	Deep orange-red	Bright orange
BISMUTH. .	Tartrate of bismuth and potassa	Deep brown	Deep brown
COBALT .	Muriate	0 but blackish	Copious black
URANIUM .	Sulphate	Brown	Blackish brown
TITANIUM .	Acid muriate	0	Black
Ditto . .	Neutral sulphate	0	Green
CERIUM			
TELLURIUM			
ARSENIC .	White oxide		
Ditto . .	Arsenic acid		
NICKEL .	Sulphate	Brown	Black
MERCURY .	Acid nitrate	Black, then gray, and black by excess of test	Black by excess of test
Ditto . .	Acid pernitrate	Ditto	Ditto
Ditto . .	Corrosive sublimate	Brown by excess of test	Ditto
RHODIUM			
PALLADIUM			
SILVER . .	Nitrate	Black, and films of reduced silver	Brown
GOLD . .	Muriate	Black and reduced gold	Yellow
PLATINUM .	Muriate	Deep brown	Pale brown

Action of Phosphorus.—Phosphorus combines with the greater number of the metals, forming a series of *metallic phosphurets.* There are three methods of forming them, either by heating a mixture of phosphorus and the metal, or projecting phosphorus upon the metal previously heated to redness; or by heating a mixture of the metal or its oxide, with phosphoric acid and charcoal; or by passing phosphuretted hydrogen over the heated metallic oxide. These phosphurets have a metallic lustre; if they contain a difficultly fusible metal, they are more fusible than the metal they contain; if an easily fusible metal, less so. They are mostly crystallizable, and totally or partly decomposable at a high temperature. The greater number of the phosphurets have only been examined by Pelletier.—*Ann. de Chim.*, tom. i. and xiii., and *Mémoires et Observations de Chimie.* The existence of compounds of metallic oxides with phosphorus appears doubtful.

The *Hypophosphites* and the *Phosphites* are, generally speaking, salts of little importance, and have been very imperfectly examined.

The *metallic phosphates* may be formed either by dissolving the oxides in phosphoric acid, or by adding a solution of phosphoric acid, or of an alkaline phosphate, to solutions of those metals which form insoluble or difficultly soluble phosphates. The greater number of the phosphates are decomposed and converted in phosphurets, by ignition with charcoal; and those containing volatile oxides are volatilized at high temperatures. The phosphates of ammonia, potassa and soda are soluble; but the greater number of these salts are difficultly soluble, and some insoluble in water: they are dissolved by phosphoric, nitric, and muriatic acids, and precipitated generally without change by ammonia. Those which are insoluble are generally decomposed by boiling with carbonate of potassa. Several of the phosphates occur in the native state, constituting some beautiful but generally rare minerals.

In the neutral phosphates the quantity of oxygen in the acid is to that in the base as 2 to 1. Thus, phosphate of soda consists of 32 soda containing 8 oxygen, and 28 phosphoric acid containing 16 of oxygen.

When phosphorus is introduced into the solutions of those metals which have but a feeble attraction for oxygen, it reduces them to the metallic state. Thus, gold, silver, and platinum are thrown down by immersing a stick of phosphorus into their respective solutions.

Action of Carbon.—Carbon unites to very few of the metals; and of the metallic carburets, one only is of importance, namely, carburet of iron, or *steel.*

Carbonic acid unites with the greater number of the metallic oxides, and forms *carbonates*, of which the distinctive characters have already been noticed: most of them are of difficult solubility, and may be formed by adding an alkaline carbonate to the metallic solution. Of the carbonates some are entirely, and others only partially, decomposed at a red heat. Carbonate of magnesia, for instance, loses the whole of its carbonic acid at a red heat; carbonate of potassa retains it; and bi-carbonate of potassa loses one-half, and passes into the state of carbonate. They are decomposed by nearly all the acids, and are then distinguished by the effervescence that ensues on the escape of carbonic acid gas.

In the neutral carbonates the proportion of oxygen in the acid is to that in the base as 2 to 1. Carbonate of potassa, for instance, consists of 22 parts of carbonic acid, containing 16 of oxygen, and 48 of potassa, containing 8 of oxygen.

The carbonates are not uncommon natural products.

Cyanogen combines with a few of the metals, and forms compounds, which we call *cyanurets;* those of potassium, mercury, silver, and palladium, have been obtained in a separate state. It appears also from the experiments of Gay-Lussac, that cyanogen combines with some of the oxides.

The *Hydrocyanates* have been but imperfectly examined; they appear peculiarly susceptible of decomposition.

Sulphocyanurets and Sulphocyanates. (See *Sulphocyanic Acid*, &c.)

Seleniurets and Seleniates. (See *Selenium*, &c.)

The *action of Boron* upon the metals has not been fully investigated; it appears, from the experiments of Descotils, (*Recherches Physico-chymiques de* MM. Gay-Lussac et Thenard) to be capable of uniting to platinum and iron. These compounds may be called *borurets.* The metallic *borates* are numerous, but mostly unimportant: a few of the borates are soluble: many of them are insoluble, and easily formed by adding solution of boracic acid, or a soluble borate to the metallic solution. The borates are generally decomposed in the humid way, by sulphuric, nitric, and muriatic acids ; but, at a red heat, the boracic acid expels the more volatile acids from their basic compounds. The presence of this acid may in many instances be detected by digesting its compounds in sulphuric acid, evaporating to dryness, and boiling the residue in alcohol, which will then be found to burn with the characteristic green flame.

Action of the Metals upon each other.—The metals may, for the most part, be combined with each other, forming a very important class of compounds, the *metallic alloys*. Various processes are adopted in the formation of alloys, depending upon the nature of the metals. Many are prepared by simply fusing the two metals in a covered crucible ; but if there be a considerable difference in the specific gravity of the metals, the heavier will often subside, and the lower part of the bar or ingot will differ in composition from the upper ; this may be to a great extent prevented by agitating the alloy till it solidifies. Mr. Hatchett found that when an alloy of gold and copper was cast into bars, the moulds being placed perpendicularly, the upper part of the bar contained more copper than the lower (*Phil. Trans.* 1803) ; and although copper and silver appear readily to combine, it is extremely difficult to form a bar of their alloy, of perfectly uniform composition throughout.

Where one of the metals is very volatile, it should generally be added to the other after its fusion ; and if both metals be volatile, they may be sometimes united by distilling them together.

It has been a question whether alloys are to be considered as compounds, or as mere mixtures ; but, in many cases, their properties leave little doubt of their being real compounds, and in some cases they are found to unite in definite proportions only ; and it is not improbable that all the alloys contain definite compounds of the metals. This is a subject, however, requiring further investigation.

The principal characters of the alloys are the following :—

i. We observe a change in the ductility, malleability, hardness, and colour. Malleability and ductility are usually impaired, and often in a remarkable degree : thus gold and lead, and gold and tin, form a brittle alloy. The alloy of copper and gold is harder than either of its component parts; and a minute quantity of arsenic added to copper renders it white.

ii. The specific gravity of an alloy is rarely the mean of its component parts, in some cases an increase, in others a diminution of density having taken place, as shown by the following Table from Thenard.—*Traité de Chimie*, vol. i. p. 394.

Alloys possessed of greater specific gravity than the mean of their components.	Alloys having a specific gravity inferior to the mean of their components.
Gold and Zinc.	Gold and Silver.
„ Tin.	„ Iron.
„ Bismuth.	„ Lead.
„ Antimony.	„ Copper.
„ Cobalt.	„ Iridium.
Silver and Zinc.	„ Nickel.
„ Lead.	Silver and Copper.
„ Tin.	Copper and Lead.
„ Bismuth.	Iron and Bismuth.
„ Antimony.	„ Antimony.
Copper and Zinc.	„ Lead.
„ Tin.	Tin and Lead.
„ Palladium.	„ Palladium.
„ Bismuth.	„ Antimony.
„ Antimony.	Nickel and Arsenic.
Lead and Bismuth.	Zinc and Antimony.
„ Antimony.	
Platinum and Molybdenum.	
Palladium and Bismuth.	

iii. The fusibility of an alloy is generally greater than that of its components. Thus platinum, which is infusible in our common furnaces, forms, when combined with arsenic, a very fusible alloy; and an alloy of certain proportions of lead, tin, and bismuth is fusible at 212°, a temperature many degrees below the melting point of its most fusible constituent.

iv. Alloys are generally more oxidizable than their constituents, taken singly; a property which is, perhaps, partly referable to the formation of an electrical combination. Where an alloy consists of two metals, the one easily and the other difficultly oxidizable, it may be decomposed by exposing it to the action of heat and air, the former metal being converted into an oxide; its last proportions, however, are often not easily separated, being protected by combination with the least oxidable metal. An alloy of three parts of lead and one of tin is infinitely more oxidizable than either of its components, and easily burns at a dull red heat.

v. The action of acids on alloys may generally be anticipated by a knowledge of their effects upon the constituent metals; but if a soluble metal be alloyed with an insoluble one, the former is often protected by the latter from the action of an acid. Thus, silver alloyed with a large quantity of gold, resists the action of nitric acid in consequence of the insolubility of the latter metal in that acid; and, in order to render it soluble, it is requisite that it should be made to form about a fourth part of the alloy, in which case the nitric acid extracts it, and leaves the gold in an insoluble film or powder.

Various classifications of the metals have been adopted by chemical authors; some dependent upon their physical, others upon their chemical properties. The former can scarcely be considered as adapted to chemical inquiry, and the latter involve numerous difficulties in consequence of the gradual transition of metals of one class into those of another. I shall consider the metals in the order in which they are set down in the following table, and which is nearly that of their respective attractions for oxygen, with the exception of the last division, which includes substances that will probably form a distinct class; but which are here ranged with the metals till their properties have been more fully examined.

1. Potassium.
2. Sodium.
3. Lithium.
4. Calcium.
5. Barium.
6. Strontium.
7. Magnesium.

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8. Manganese.
9. Iron.
10. Zinc.
11. Tin.
12. Cadmium.

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13. Copper.
14. Lead.
15. Antimony.

16. Bismuth.
17. Cobalt.
18. Uranium.
19. Titanium.
20. Cerium.
21. Tellurium.

22. Arsenic.
23. Molybdenum.
24. Chromium.
25. Tungsten.
26. Columbium.

27. Nickel.
28. Mercury.
29. Silver.
30. Gold.
31. Platinum.
32. Osmium.
33. Iridium.
34. Rhodium.
35. Palladium.

36. Silicium.
37. Alumium.
38. Zirconium.
39. Glucium.
40. Yttrium.

Of these metals the first seven produce alkaline oxides which are very difficult of reduction; and they rapidly decompose water at all temperatures, a character which announces their powerful attraction for oxygen: the next five decompose water when their temperature is raised to redness; the nine following do not decompose water at a red heat; nor do the next five, which produce acids by uniting to oxygen. The oxides of these twenty-seven metals are not reducible by heat alone, though some of them, when heated, give out a portion of oxygen. The nine metals which next follow, osmium excepted, have a comparatively feeble attraction for oxygen; and when their oxides are heated, they are reduced to the metallic state. The last five metals are placed in the list from analogy; they are only known in the state of oxides, which have not hitherto been reduced.

Section I. Potassium.

This metal was discovered in 1807 by Sir Humphry Davy (*Phil. Trans.*, 1808). He obtained it by submitting caustic potassa, or potash, to the action of Voltaic electricity: the metal was slowly evolved at the negative pole. By this process, however, it could only be procured in very minute quantities ; and various other methods have been devised, of which the best is that described by Gay Lussac and Thenard (*Recherches Physico-chymiques.*) It is as follows :—

A sound and perfectly clean gun-barrel is bent, as shown in the annexed sketch. It is then covered with an infusible lute between the letters o and e (*Fig.* 1), and the interior of the luted part is filled with clean iron turnings. Pieces of fused potassa are then loosely placed in the barrel between e and c. a a is a copper tube and small receiver, which are adapted to the extremity o, and to each other, by grinding. This apparatus is next transferred to the furnace, arranged as shown in *Fig.* 2, x and t representing two glass tubes dipping into mercury. The furnace is supplied with air by a good double bellows entering at b, and a small wire basket, g, is suspended

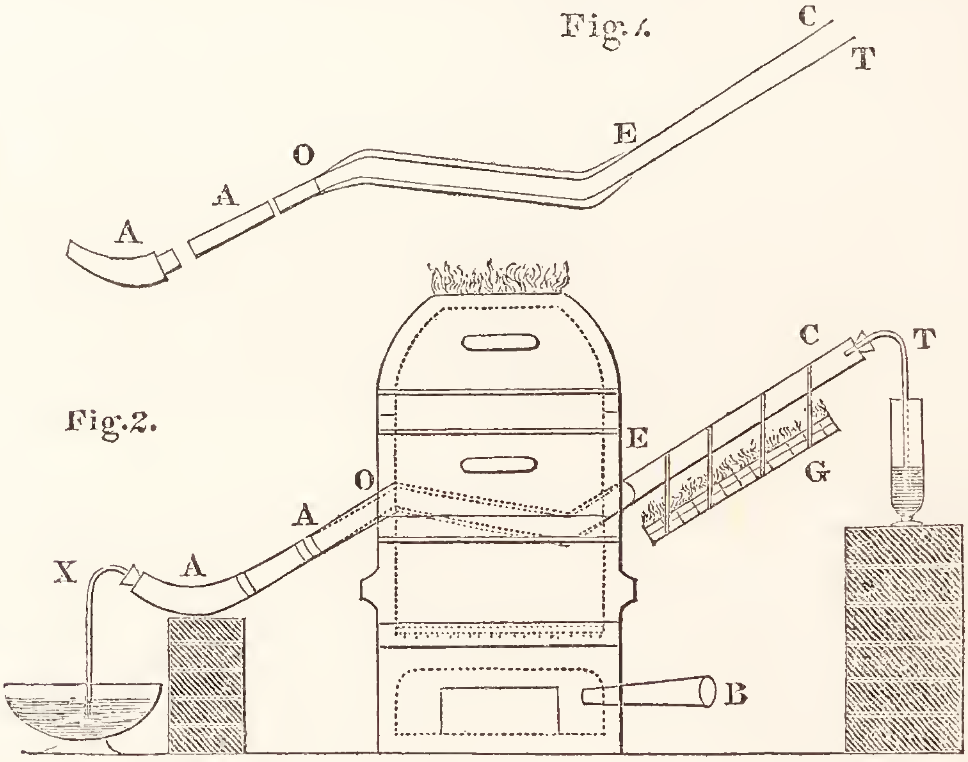
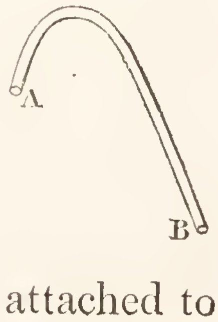


Fig. 1.
Fig. 2.

below the space E C. The part of the barrel in the furnace is now cautiously raised to a white heat, and the escape of air by the tube X shews that all is tight. Some burning charcoal is then put at the end E, of the cage G, which causes a portion of potassa to liquefy and fall into the low part of the barrel upon the iron. Hydrogen gas instantly escapes by the tube X, and attention must now be had to keep the copper tubes A A cool, by laying wet cloths upon them. When the evolution of gas ceases, fresh charcoal is placed under the potassa, and so on till the whole has passed down; if too much potassa be suffered to fall at once, the extrication of gas at X will be very violent, which should be avoided. If the space between A and O should become stopped by potassium, gas will issue by the tube T (which must always be under a greater pressure of quicksilver than the tube X), and it may be fused by applying hot charcoal to the tube, when the gas will again appear at X and cease at T. When the operation is concluded, the tubes X and T are removed, and corks quickly applied to the holes; and when the apparatus is cool, the barrel is carefully removed from the furnace, and a little naphtha suffered to run through it. The potassium is found in globules in the tube and receiver A A, and considerable portions often lodge at O. The success of this operation is certain, if the heat has been sufficient; but the barrel, if not very carefully covered with lute, is apt to melt, and much, if not the whole, of the product is lost.

Besides the above, there are several other methods of obtaining potassium, among which, those recommended by M. Brunner deserve particular notice (*Quarterly Journal*, XV. 379), although we have not been able to succeed to the extent which he describes. He employs a spheroidal wrought-iron bottle, of a capacity between a pint and a quart, and a piece of gun-barrel of the annexed shape is fitted to its neck by grinding at the end A. When the bottle is charged and properly luted it is placed in a proper furnace, nearly perpendicularly, and so that the greater part of the tube may be exposed to heat (it being protected by coils of iron wire rolled round it), while the end B projects, and has attached to



it a copper receiver with a small safety tube. This receiver, when in use, is about half filled with naphtha, and kept cold by ice or cold water. Four ounces of fused caustic potassa are then introduced into the cleaned and heated retort, in small portions, alternately with 6 ounces of clean iron-turnings broken in a mortar, and 1 ounce of powdered charcoal; and this mixture is covered by 2 ounces more of iron-turnings: the bottle, carefully luted, is placed in the furnace, and a glass tube inserted into the protruding barrel at B. As soon as the whole acquires a bright red heat, inflammable gas is evolved, which burns with a violet flame, and shortly after the green vapour of potassium is seen in the glass tube, which is then removed, and the copper receiver substituted, so that the end B may dip into the naphtha. When the evolution of gas ceases, the fire is extinguished, and the receiver carefully removed. A very successful result furnished 150 grains of potassium, in small globular masses.

In another experiment the mixture in the retort consisted of 8 ounces of pure and fused carbonate of potassa, 6 of iron-turnings, finely bruised, and 2 of charcoal: from these 140 grains of potassium were obtained. Calcined tartar was also sometimes employed instead of other forms of potassa.

The theory of these operations is by no means clearly understood in its minute details. When pure hydrate of potassa is employed in the gun-barrel experiment, more than a fourth of its weight of potassium is never obtained; the remainder is chiefly found in combination with the produced oxide of iron, forming a hard brittle compound, difficultly acted on by water. The evolution of potassium is evidently dependent upon the attraction of the iron at a high heat for oxygen; the water of the potassa is at the same time decomposed, and possibly the nascent hydrogen may perform its part in the reduction: the readiness with which potassium assumes the elastic state at high temperatures also contributes to its evolution; yet, when the exceedingly powerful attraction of potassium for oxygen is considered, the process is, as to its theory, obscure.

Obtained by the aid of charcoal, potassium generally contains a little carbon, which may be separated by redistilling it in a small iron or even glass retort, with its beak dipped into naphtha, but this is a troublesome process, and generally attended by some loss of the metal.

M. Wohler has also described a modification of the potassium apparatus, and a peculiar receiver for its condensation, contrived by Berzelius, of which a description will be found in the twenty-second volume of the *Quarterly Journal*, p. 206. In all these arrangements it is a point of importance to have the tubes, through which the metal passes into the naphtha, as short as possible, and of a sufficient diameter, otherwise they are apt to become plugged up *.

Potassium is a white metal of great lustre. It instantly tarnishes by exposure to air, and is gradually converted into an oxide. It is ductile, and of the consistency of soft wax. Its specific gravity is about 0.85. It is most conveniently preserved in naphtha, either by keeping it immersed in that liquid, or by dipping the pieces of metal into it, and keeping them thus varnished, in a small well-stopped phial. When used, the exterior must be scraped; or the naphtha may be driven off by a gentle heat. At 150° it enters into perfect fusion; and at a bright red heat it boils and rises in green vapour. At 32° it is a hard and brittle solid, of a crystallized texture. If heated in air it burns with a brilliant white flame. It is an excellent conductor of electricity and of heat.

Potassium and Oxygen.—The attraction of potassium for oxygen appears, under most circumstances, to exceed that of all other bodies; it is, consequently, the most powerful deoxidizing agent which we possess. It appears to form two definite compounds with oxygen, which we may call the *protoxide* and *peroxide;* Berzelius admits a *suboxide*, but it is probably a mixture of potassium with the protoxide. When potassium

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* In these modes of obtaining potassium it sometimes happens that a peculiar product is formed, which M. Gmelin has called *Croconic Acid*, and which he considers as a compound of carbon, oxygen, and hydrogen. The nature of this body has not been sufficiently examined; but it is not improbable that where crude tartar has been used it may contain nitrogen, and be identical with *carbazotic acid* (See INDIGO). M. Gmelin's paper is in the *Annales des Mines*, xii. 164; and an abstract of it is given in the *Quarterly Journal*, xxii. 209. The basis of the hydrocroconic acid is by some considered as a peculiar and definite compound of carbon and oxygen, containing less oxygen than carbonic oxide; but experiments, at present, scarcely warrant such a conclusion.

is thrown into water it instantly takes fire; hydrogen gas is evolved, and *protoxide of potassium,* or *potassa,* is found dissolved in the water. The quantity of hydrogen evolved in this experiment becomes the indicator of the proportion of oxygen which has been transferred to the metal; 100 parts of potassium are thus found to absorb 20 of oxygen; and if this be considered a protoxide, then 20 : 100 :: 8 : 40,—so that 40 will be the number representing potassium; and the protoxide, in its dry or anhydrous state, consists of

1 proportional of potassium . . . . = 40
1 „ oxygen . . . . = 8
Equivalent of the protoxide . . . . = 48

Potassa, in the state it is usually met with in laboratories, contains a considerable portion of water, as is rendered manifest by the action of iron at high temperatures; and there always remains in the barrel, after the above experiment, a large portion of *dry potassa* combined with oxide of iron. To obtain dry potassa, or *anhydrous protoxide of potassium* in its pure state, the metal may be exposed, at common temperatures, to the action of perfectly dry air or oxygen; or 1 part of potassium may be fused with 1.4 of the hydrated protoxide. It is a grey substance, fusible at a red heat, and volatile at a white heat. It combines very energetically with water to produce a hydrate, and what is commonly called caustic or pure potassa, is in fact this hydrate, composed of

1 proportional of anhydrous protoxide . . . . . . = 48
1 „ water . . . . = 9
Equivalent of hydrated protoxide of potassium, or protohydrate of potassa . . . . = 57

The *Hydrated Protoxide* or *Caustic Potash* is procured in our laboratories by decomposing carbonate of potassa by lime. The best process consists in boiling in a clean iron vessel, pure carbonate of potassa, with half its weight of pure quick lime, in water. The lime is gradually added to the boiling alkaline solution, which is kept constantly stirred, and towards the end of the operation it is tested, by filtering a small portion, and pouring it into three or four times its bulk of dilute nitric acid: if there be no effervescence, sufficient lime has been used; but if carbonic acid escapes, the ebullition with lime must be continued until the tested portion shows no signs of carbonic acid. The whole is then allowed to remain quiet, that the lime may subside; and the clear liquor or *ley* being poured off, is strained through clean linen, concentrated by evaporation, again strained, and set by in a well-stopped bottle till it admits of being decanted, perfectly clear from any sediment. The clear solution is to be evaporated to dryness, in a polished iron or pure silver basin. It is often cast into sticks for the use of surgeons, who employ it as a caustic, and in this state it generally contains some peroxide, and therefore evolves oxygen when dissolved in water. It is the *potassa fusa* of the *London Pharmacopœia.* It may be further purified by the action of alcohol, which dissolves the pure hydrate, and leaves earthy and other impurities; the alcohol is then driven off by heat. In this case the alcohol is always in some measure acted upon by the potassa, and a portion of carbonaceous matter deposited, so that it should be allowed to remain as short a time as possible combined with the alkali. Having obtained the dry caustic alkali by lime, it may be boiled in a silver basin with highly rectified alcohol for a few minutes, and then set by in a stopped phial; when the impurities are deposited, the alcoholic solution may be poured off and rapidly evaporated to dryness in a silver basin as before; or if the quantity of alcohol be considerable, it may be distilled off in a silver alembic with a glass head: the heat may then be raised so as to fuse the potassa, which, on cooling, should be broken up and preserved in well-closed phials.

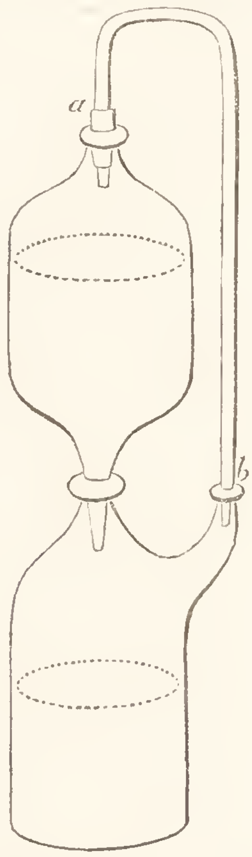
Hydrate of Potassa thus purified is white, very acrid and corrosive, and at a bright red heat evaporates in the form of white acrid smoke. At a white heat it is decomposed by charcoal, and carburetted hydrogen, carbonic oxide, and potassium are formed. It quickly absorbs moisture and carbonic acid from the air, and at 60° one part of water dissolves two. It may be crystallized in octoëdrons, by keeping a strong aqueous solution of it for some time in close vessels. They contain much water of crystallization. It is highly alkaline, powerfully reddening turmeric, and converting several vegetable blues to green: it also acts energetically upon the greater number of organic products, and unites with the fat oils to form soap. Being exclusively procured from vegetables, it was formerly called *vegetable alkali;* but it also exists in certain minerals, and in a few animal secretions. When touched with moist fingers it has a soapy feel, in consequence of its action upon the cuticle. In the fused state it produces heat when dissolved in water; but in its crystallized state it excites considerable cold, especially when mixed with snow. At a natural temperature of 30°, M. Lowitz found that equal weights of crystallized potassa and snow depressed the thermometer 45°.—*Annales de Chimie,* xxii.

The oxides of manganese, zinc, tin, lead, antimony, cobalt, arsenic, molybdenum, tungsten, and nickel, are soluble in aqueous solution of potassa.

The *Liquor Potassæ* of the *Pharmacopœia* is directed to be prepared as follows:—"Take of subcarbonate (carbonate) of potassa a pound; fresh lime, half a pound; boiling distilled water, a gallon. Dissolve the subcarbonate in two pints of the water; add the remaining water to the lime; mix the hot liquors together; then set the mixture by in a covered vessel, and after it has cooled, filter the solution through a cotton strainer. If effervescence be excited by dropping any diluted acid into the solution, more lime must be added, and the solution again strained. A pint of this solution ought to weigh 16 ounces troy." Its specific gravity in that case is 1.056.

Whilst the solution of potassa is filtering, it is apt to absorb a little carbonic acid from the air, which may be prevented by covering the funnel with a plate of glass, and receiving it into a bottle as nearly air-tight as possible; or the annexed filtering apparatus, contrived by Mr. Donovan (*Annals of Philos.* xxvi. 115), may be used. It consists of two glass vessels connected by a tube, made air-tight by perforated corks at the junctions *a* and *b*. The upper vessel terminates in a conical pipe, ground into the lower one, and into which is stuffed a piece of coarse linen.

In all cases where solutions of potassa are employed, it must be recollected that they gradually act upon glass, especially upon common white glass—hence green glass vessels are preferable: but where alkaline solutions are to be exposed to heat, even these communicate some impurity, and in such cases vessels of pure silver can only be relied upon.



It may sometimes be useful to know the quantity of real potassa contained in watery solutions of different specific gravities; and the following results of Mr. Dalton's experiments, in reference to this question, are probably near the truth:—

Specific Gravity.	Potassa per Cent.	Boiling Point.
1.68	51.2	320°
1.60	46.7	290
1.52	42.9	276
1.47	39.6	265
1.44	36.8	255
1.42	34.4	246
1.39	32.4	240
1.36	29.4	234
1.33	26.3	229
1.28	23.4	224
1.23	19.5	220
1.19	16.2	218
1.15	13.	215
1.11	9.5	214
1.06	4.7	213

Peroxide of Potassium.—When potassium is burned in a silver spoon in oxygen gas, a yellow fusible substance is obtained, which, on cooling, acquires a scaly crystalline appearance. It consists, according to Gay-Lussac and Thenard, of

1 proportional of potassium . . .		= 40
3 proportionals of oxygen . .	(8 × 3)	= 24
Equivalent of peroxide of potassium . .		= 64

This substance has some singular properties; it supports the combustion of most of the inflammables, and when heated in hydrogen gas, diminishes its bulk and forms water: it decomposes ammonia under the same circumstances. When put into water a copious effervescence ensues, arising from the escape of oxygen gas, and a solution of potassa is obtained. When hydrate of potassa is fused in an open crucible, a portion of its water is disengaged, and oxygen absorbed, so as to form this peroxide; and hence it is, that common caustic potassa almost always effervesces, and gives out oxygen upon the affusion of water. When potassium is dropped into melted nitre, the peroxide is also formed; likewise by passing oxygen over potassa heated to redness.

Chlorine and Potassium act very energetically on each other, and produce the white compound which has been called *muriate of potash*, but which is a true *chloride of potassium*, consisting of

1 proportional of potassium . .	= 40
1 „ chlorine . . .	= 36
Equivalent of chloride of potassium . .	= 76

When potassium is heated in gaseous muriatic acid, this compound is formed, and hydrogen is evolved; an experiment already adverted to under the article *Muriatic Acid* (p. 180). It dissolves without decomposition in three parts of water at 60°. One part of the powdered salt stirred into four parts of cold water produces a considerable depression of temperature. It crystallizes in cubes, which are anhydrous; its taste is saline and bitter. In old pharmacy it was called *digestive salt of Sylvius*; also, *regenerated sea-salt*. It is soluble in alcohol. It is volatile, and at a high temperature, and intensely heated in open vessels, evaporates in the form of white smoke.

Chlorate of Potassa is formed by passing chlorine through a solution of potassa. Chloride of potassium is one of the results, the other is *chlorate of potassa,* a salt in brilliant rhomboidal tables (formerly called *oxmuriate of potash*). Its crystalline forms have been described by Mr. Levy (*Quarterly Journal*, xv. 286).

This salt is prepared, upon the large scale, by charging one or two Wolfe's bottles with solution of carbonate of potassa, and passing chlorine slowly through it, at the lowest convenient temperature: the gas is absorbed, and the liquor effervesces chiefly from the escape of carbonic acid; when this has ceased, the liquor may be put aside in a cold dark place for about 24 hours, when it will be found to have deposited a considerable portion of the crystallized chlorate, which may be taken out, drained, and purified by solution in hot water, which, during cooling, again deposits the salt in white crystalline scales. The mother liquor, from which more of the salt may be obtained by evaporation, is generally of a pinkish hue, from the presence of a trace of manganese; but this tint disappears when sufficiency of chlorine has been passed in to saturate it, and it acquires a brownish hue *. Solution of pure potassa absorbs the gas more readily than the carbonate, but nearly with the same phenomena, and in either case care must be taken that the tube conveying the chlorine does not become stopped up by the salt, which is apt to happen if it be not sufficiently capacious.

To understand the theory of this process we must recollect that chloric acid is a compound of one proportional of chlorine and five of oxygen, and that chloride of potassium consists of one proportional of chlorine and one of potassium, and that potassa contains one proportional of oxygen and one of potassium: it follows, then, that five proportionals of chlorine acting upon five of potassa will expel five of oxygen, which, uniting with one of chlorine, will form one proportional of chloric acid, and this uniting to a proportional of the undecomposed potassa will form chlorate of potassa, as shown in the following diagram:—

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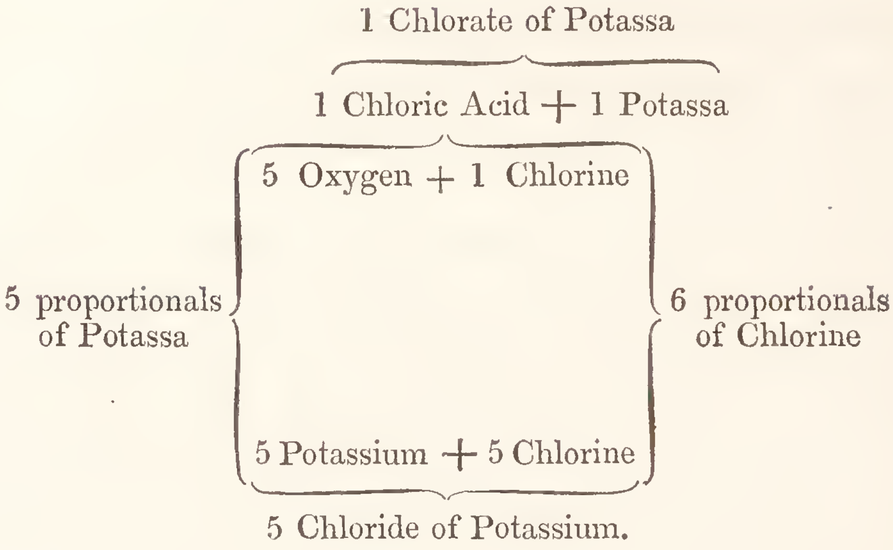
* In this process, the carbonic acid is expelled when excess of chlorine is passed into the solution: by particular management chlorine may be retained in a solution of carbonated alkali, forming a very peculiar compound. See *Carbonate of Soda.*



It appears, therefore, that five proportionals of potassa will require six of chlorine to be consumed in the formation of five proportionals of chloride of potassium, and one proportional of chloric acid. The elements of the water are not concerned in the formation of these products, but that fluid performs the important office of enabling the different elements to act upon each other in their nascent states.

The taste of this salt is cooling and austere. When pure its aqueous solution is not rendered turbid by nitrate of silver. When triturated it appears phosphorescent. It is anhydrous. When exposed to a dull heat it decrepitates, fuses, gives out oxygen, and chloride of potassium remains. It is soluble in 18 parts of cold and 2.5 of boiling water. It acts very energetically upon many inflammables, and triturated with sulphur, phosphorus, and charcoal, produces inflammation and explosion. A mixture of three parts of this chlorate with one of sulphur, detonates loudly when struck upon an anvil with a hammer, and even sometimes explodes spontaneously; hence it should not be kept ready mixed. Chlorate of potassa was proposed by Berthollet as a substitute for nitre in gunpowder. The attempt was made at Essone in 1788; but, as might have been expected, no sooner was the mixture of the chlorate with the sulphur and charcoal submitted to trituration, than it exploded with violence, and proved fatal to several people. With phosphorus the detonation is dangerously violent. The experiment is best made, by wrapping a grain of phosphorus and two of the chlorate in a small piece of paper, and striking them a blow with a hammer, upon an anvil. The phosphorus is generally thrown about in an inflamed state. These phenomena depend upon the decomposition of the chloric acid.

The action of sulphuric acid upon chlorate of potassa has already been adverted to. (See *Oxides of Chlorine.*) If, instead of distilling the yellow mixture of the acid and chlorate with the caution there described, it be heated to about 150°, it suddenly explodes. The theory of the production of chloric oxide is more explicitly described in the next page.

When sulphuric acid is dropped upon mixtures of this salt and combustibles, instant ignition ensues in consequence of the evolution of oxide of chlorine. A mixture of sugar and the chlorate thus treated is immediately kindled with a red and blue flame; and a mixture of sulphuret of antimony and the salt suddenly deflagrates with a bright puff of flame and smoke: the latter mixture requires to be cautiously made, as it often takes fire by mere trituration. Matches tipped with some of these inflammable mixtures are now in common use, and are inflamed by the contact of sulphuric acid, which is most conveniently applied by putting some asbestus into a small well-stopped phial, and moistening it with sulphuric acid: the match is rapidly dipped into the phial and inflames on touching the asbestus, without the risk of spirting about the acid. Berzelius gives the following as the best composition for the match: 30 parts of powdered chlorate of potassa, 10 of powdered sulphur, 8 of sugar, 5 of gum-arabic, and a little cinnabar. The sugar, gum, and salt, are first rubbed together into a paste with a sufficiency of water; the sulphur is then added, and the whole being thoroughly beaten together, small brimstone matches are dipped in, so as to retain a thin coat of the mixture upon their sulphuretted points: they should be quite dry before they are used. One of the compounds occasionally employed in percussion gun-locks is a similar composition: 10 parts of gunpowder are rubbed with water, and the soluble part poured off; the remaining paste is then mixed with 5¼ parts of finely-powdered chlorate of potassa, and a drop of it put into each of the small copper caps adapted to the peculiar tubular touchhole of the gun; a blow being struck upon the cap the powder is inflamed, and communicates to that in the barrel. The great disadvantage of this compound is, that it forms products which must soon rust the touchhole and surrounding parts: fulminating mercury is, therefore, now generally substituted for it.

When sulphuric or nitric acids are poured upon similar mixtures of chlorate of potassa and certain combustibles under water, by means of a long funnel, inflammation also ensues.

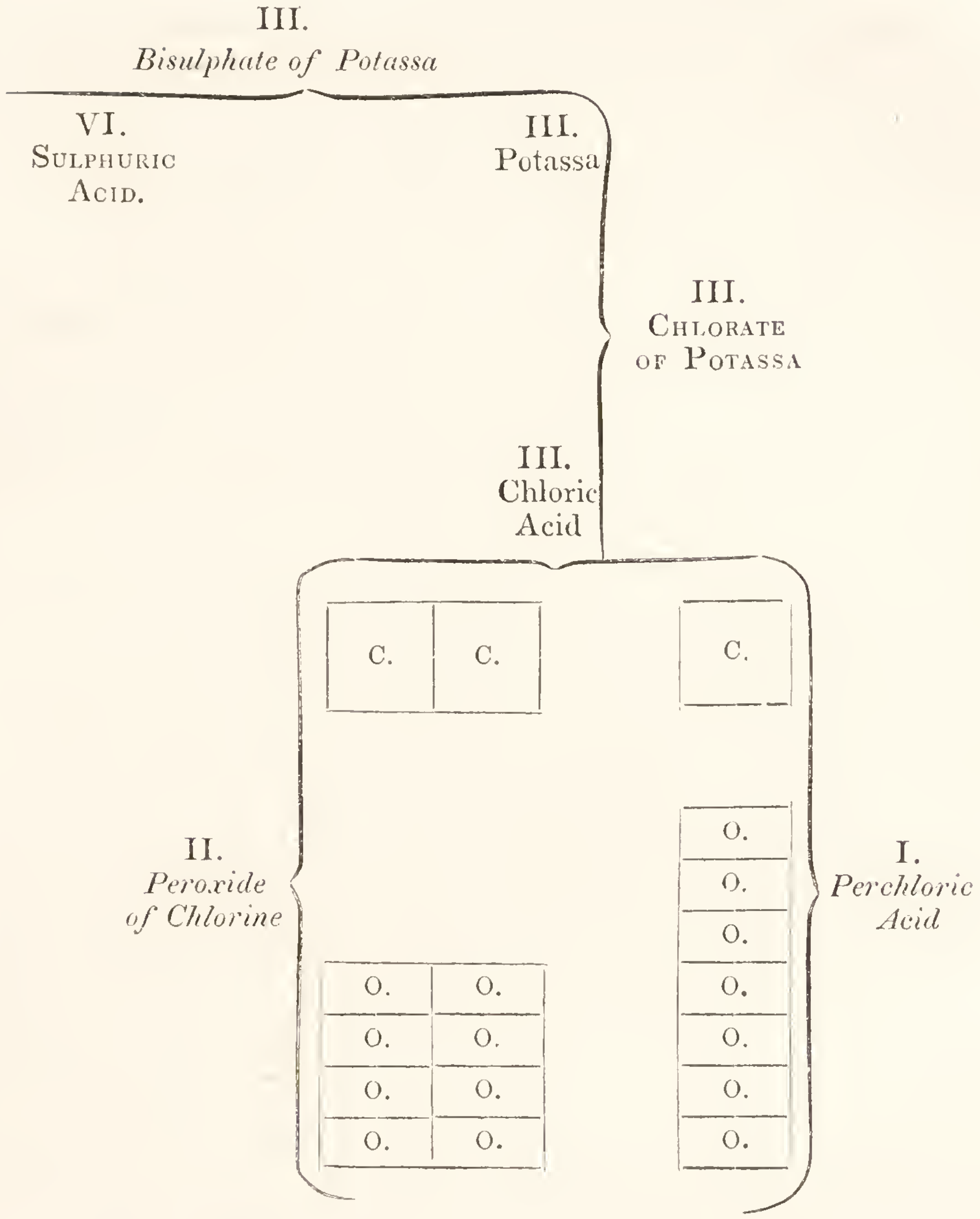
A few grains of chlorate of potassa put into a teaspoonful of muriatic acid, and then diluted with water, form an extemporaneous bleaching liquor.

Chlorate of potassa consists of one proportional of chloric acid and one of potassa, or 76 C. A. + 48 P. = 124. Its ultimate components, therefore, are

6 proportionals of oxygen (5 in the acid and 1 in the alkali)	= 48
1 proportional of chlorine . . .	= 36
1 „ potassium . . .	= 40
Equivalent of chlorate of potassa . .	=124

Oxychlorate of Potassa may be formed by moistening one part of chlorate of potassa with three of sulphuric acid, and subsequently carefully heating the mass till it becomes white, and the oxide of chlorine is expelled: in this state it consists of bisulphate and oxychlorate of potassa, which may be separated by solution and crystallization, the former being much more soluble in cold water than the latter salt.

In reference to the production of peroxide of chlorine and perchloric acid, as the result of the action of sulphuric acid upon chlorate of potassa, the following diagram may, perhaps, be useful. The original substances are printed in capitals, the components in common type, and the resulting compounds in italics; the volumes of oxygen and of chlorine being shown by the usual symbols of bulks which I have elsewhere employed. The Roman numerals denote the number of proportionals presumed to be employed.



Thus it appears that six proportionals of sulphuric acid acting upon three of chlorate of potassa form three of bisulphate of potassa, and detach three of chloric acid, the elements of which are three of chlorine and fifteen of oxygen: of these, two of chlorine and eight of oxygen form two of peroxide of chlorine; and the remaining one of chlorine and seven of oxygen form perchloric acid. If instead, as in the above diagram, of considering the mere formation of perchloric acid, we refer to the formation of perchlorate of potassa, we must assume that the oxygen is transferred to the chloric acid of an undecomposed portion of chlorate of potassa, and so converts it into perchlorate.

Oxychlorate of potassa does not change vegetable colours, nor is it altered by exposure to air. It requires rather more than 50 parts of water at 60° for its solution. It is insoluble in alcohol: it detonates slightly when rubbed with sulphur: it crystallizes in elongated octoëdrons. When mixed with its own weight of sulphuric acid, and distilled at 280°, solution of oxychloric acid passes over. It may be decomposed by exposure to a temperature of 412°. Oxygen is given off, equal to 0.44 per cent. of the weight of the salt, and chloride of potassium remains in the retort. This salt is thus found to consist of one proportional of oxychloric acid 92 + 1 proportional potassa = 48, and its representative number is therefore = 140.

Iodide of Potassium.—Iodine and potassium act upon each other very energetically, and a crystalline compound is obtained, white and fusible. When hydriodic acid is saturated by potassa, and the solution carefully evaporated, anhydrous prismatic crystals of the iodide (or as it is usually called in medicine, *hydriodate of potassa*) are obtained. The readiest mode of procuring this compound consists in dissolving iodine in solution of potassa, till it begins to assume a brown colour: on evaporating to dryness, and fusing the residuary salt, a pure iodide of potassium remains. If, instead of fusing the products, the solution be carefully evaporated nearly to dryness, and alcohol poured upon it, the iodide is dissolved, and there remains a salt insoluble in alcohol, which is iodate of potassa, and which, at a red heat, evolves oxygen, and becomes iodide of potassium. The action of iodine upon the alkali appears in all respects to correspond with that of chlorine.

Iodide of potassium consists of

1 proportional of potassium . . .	= 40
1 „ iodine . . .	= 125
Equivalent of iodide of potassium . . .	= 165

The aqueous solution of iodide of potassium dissolves a considerable portion of iodine; this solution is sometimes used in medicine: it is of a deep brown colour.

Iodate of Potassa, obtained as just described, is a white difficultly soluble salt, requiring about 14 parts of water at 60° for its solution: at a red heat, it gives out between 22 and 23 *per cent.* of oxygen, and is converted into iodide of potassium. It is insoluble in alcohol; it forms small and permanent prismatic crystals, composed of

1 proportional of potassa . .	= 48
1 ,, iodic acid . .	= 165
Equivalent of iodate of potassa . .	= 213

Potassium and Bromine.—These substances act intensely upon each other, evolving heat and light, and producing explosion. When bromine is dropped into solution of potassa, and the mixture evaporated to dryness, a *bromide of potassium* is also obtained: it is a white crystallizable and fusible substance, composed of

1 proportional of potassium . .	= 40
1 ,, bromine . .	= 75 ?
Equivalent of bromide of potassium .	= 115

When ethereal solution of bromine is agitated with liquid potassa, the yellow colour disappears, and bromate of potassa and bromide of potassium are the results. The action, therefore, of bromine is here analogous to that of chlorine and iodine.

Bromate of Potassa separates in the form of a crystalline powder, when bromine and solution of potassa are mixed in sufficient quantities. It scintillates on a hot coal, like nitre, and evolving oxygen, becomes bromide of potassium. It is slightly soluble in alcohol, readily soluble in water, and crystallizes in needles: mixed with sulphur, it detonates by a blow. Its solution occasions a white precipitate in nitrate of silver. (Balard, *Quarterly Journal*, xxii. 389.)

Potassium and Fluorine.—When hydrofluoric acid is saturated with potassa, and evaporated to dryness, a deliquescent and very difficultly crystallizable compound is obtained, which must be regarded as a *fluoride of potassium*, consisting probably of

1 proportional of potassium . .	= 40
1 ,, fluorine . . .	= 16
Equivalent of fluoride of potassium .	= 56

This fluoride bears an intense heat without change.

Berzelius has described an apparently peculiar compound obtained by dissolving the above fluoride in hydrofluoric acid, and evaporating to dryness in a platinum vessel: it is crystallizable, readily soluble in water, and when heated to incipient redness is decomposed, hydrofluoric acid being evolved, and fluoride of potassium remaining.

Potassium and Hydrogen.—When potassium is heated in hydrogen, it absorbs a portion of the gas, and produces a gray infusible *hydruret*, destitute of lustre, and burning vividly when heated in air or oxygen gas. When heated, *per se*, it evolves hydrogen; and the same change takes place in the contact of mercury. When hydrogen and potassium are passed together through a white-hot tube, the gas dissolves the metal, and produces a spontaneously inflammable *potassiuretted hydrogen gas*. Potassiuretted hydrogen is also produced when potassium is thrown upon water, and is the cause of the red flame and white fumes produced during its combustion under such circumstances. Both these compounds are usually formed during the operation for obtaining potassium by the gun-barrel.

Nitrate of Potassa—Nitre—Saltpetre.—This salt is an abundant natural product, and is principally brought to this country from the East Indies, where it is produced by lixiviation from certain soils.

The greater part of the rough nitre imported from the East Indies is in broken crystals of a brown colour, and more or less deliquescent: exclusive of other impurities, it often contains a very considerable proportion of common salt, which, re-acting upon the nitre, induces the production of a portion of nitrate of soda and chloride of potassium.

In Germany and France it is artificially produced in what are termed nitre-beds. Thenard (*Traité de Chemie Elémentaire*, tom. ii. p. 511) has described the French process at length. It consists in lixiviating old plaster rubbish, which, when rich in nitre, affords about five per cent. Refuse animal and vegetable matter which has putrefied in contact with calcareous soils produces nitrate of lime, which affords nitre by mixture with sub-carbonate of potassa. In the same way it is abundantly produced in some parts of Spain. Exudations containing saltpetre are not uncommon upon new walls, where it appears to arise from the decomposition of animal matter contained in the mortar. It was long ago shown by Glauber, that a vault plastered over with a mixture of lime, wood-ashes, and cows' dung, soon becomes covered with efflorescent nitre, and that, after some months, the materials yield, on lixiviation, a considerable proportion of that salt.

Nitre crystallizes in six-sided prisms, usually terminated by dihedral summits. Its primitive form is a right rhombic prism, the measurement and modifications of which have been given by Mr. Levy (*Quarterly Journal*, xv. 284). The crystals are large and smooth when obtained from a great mass of solution, but irregular and striated when formed in smaller quantities, The large crystals are very sensible to changes of temperature, and when handled generally crack transversely; so that it is difficult to preserve them entire. They are not altered by exposure to air. According to Bergman, it dissolves in 7 parts of water at 60°, and in its own weight at 212°; but these proportions are not correct: La Grange states that 1 part of nitre dissolves in between 3 and 4 of water at 60°, and in half its weight at 212°. Gay-Lussac has shown that the solubility of nitre varies extremely with temperature: at 0°, 100 parts of water dissolve 13.2 of the salt; at 77°, the salt dissolved by 100 of water is 38 parts; at 132°, it amounts to 97 parts; at 176°, to 169 parts; at 210°, to 236 parts; and at 212° to 246 parts. It is insoluble in pure alcohol. The crystals of nitre, though the salt is anhydrous, always contain interstitial water; so that they appear moist when powdered, and lose weight on drying. The taste of nitre is cooling and peculiar, and it is used in medicine in small doses, as a diuretic and sedative: in doses of from half an ounce to an ounce it is eminently poisonous, exciting violent spasms, vomiting, bloody stools, convulsions, and generally proving fatal. In such cases, viscid mucilaginous drinks with opium and cordials are the most effective restoratives. This salt consists of

1 proportional of potassa . . .	=	48
1 „ nitric acid . . .	=	54
Equivalent of nitrate of potassa . .	=	102

Its ultimate components are,

1 proportional of potassium . . . = 40
1 „ nitrogen . . . = 14
6 proportionals of oxygen (5 in the acid and 1 in the potassa, 8 × 6) . . . = 48
102

At a temperature of about 600°, nitre fuses without undergoing change of composition, and congeals, on cooling, into a white striated mass. Sometimes it is cast into small balls or cakes, called *sal prunella*, a name derived from the circumstance of its having been occasionally stained of a plum colour. At a red heat, nitre is slowly decomposed; and if distilled in an earthen retort or gun-barrel, it affords abundance of oxygen gas, one pound yielding about 12,000 cubic inches of sufficient purity for many common experiments in which that gas is used; it is of course mixed with a portion of nitrogen. In this decomposition the nitre is first converted into *nitrite of potassa*, which is deliquescent; and afterwards, according to Berzelius, compounds are formed of potassa with nitric and nitrous oxides.

Nitre is rapidly decomposed by charcoal at a red heat; and if excess of charcoal be used, the results are carbonic oxide and acid, nitrogen, and subcarbonate of potassa, formerly called *nitrum fixum*, and *white flux*.

The old chemists used to perform this detonation in retorts connected with capacious receivers, which were generally blown to pieces; sometimes they succeeded in obtaining a little acidulated water, which they called *clyssus of nitre*, and attributed to it wonderful medical virtues. These mixtures of nitre and charcoal form the basis of a variety of compositions used for fireworks, the rapidity of the combustion being modified by the relative proportion of the charcoal.

When phosphorus is thrown upon nitre, and inflamed, a vivid combustion ensues, and a phosphate of potassa is formed. Sulphur sprinkled upon hot nitre burns, and produces a mixture of sulphate and sulphite of potassa. This salt used formerly to be employed in medicine, under the name of *Glaser's polychrest salt*. The combustion of a mixture of nitre and sulphur has already been described as the source of sulphuric acid (p. 252). When a mixture of two parts of nitre and one of muriate of ammonia are heated to redness, chloride of potassium, water, chlorine, muriatic acid and a little nitrous acid are the results, and nitrogen gas is copiously evolved. (*Soubeiran*, *Journal de Pharmacie*, 1827, p. 321.) Most of the metals, when in filings or powder, detonate and burn when thrown on red-hot nitre; some of the more inflammable metals produce in this way a considerable explosion.

A mixture of three parts of nitre, two of dry subcarbonate of potassa, and one of sulphur, forms *fulminating powder.* If a little of this compound be heated upon a metallic plate, it blackens, fuses, and explodes with much violence, in consequence of the rapid action of the sulphur upon the nitre, and the sudden evolution of nitrogen in its gaseous form.

Gunpowder consists of a very intimate mixture of nitre, sulphur, and charcoal. The proportions vary. The following are those usually employed:—

	Common gunpowder.	Shooting powder.	Shooting powder.	Miner's powder.
Saltpetre	75.0	78	76	65
Charcoal	12.5	12	15	15
Sulphur	12.5	10	9	20

The latter contains the smallest quantity of saltpetre, as it requires less *quickness* or *strength.* The ingredients are *perfectly* mixed, moistened, beaten into a cake which is afterwards broken up, granulated, dried, and for the finest powder polished by attrition. The violence of the explosion of gunpowder depends upon the sudden production of gaseous matter, and of intense heat, resulting from the action of the combustibles upon the nitre. Carbonic oxide, carbonic acid, nitrogen, and sulphurous acid, are the principal gaseous results; and the solid residue consists of carbonate, sulphate, and sulphuret of potassa, and charcoal.—(Cruickshanks, *Nicholson's Journal*, iv. See also the same Journal, xiii. 277.)

Gunpowder may, it is said, be inflamed by a violent blow; if mixed with powdered glass, or any other harder substance, and struck with a heavy hammer upon an anvil, it almost always explodes. It readily burns under water, and by using a slowly burning powder, such as squibs are filled with, inflamed in a tube of copper, the gaseous products may be collected over water in the pneumatic trough.

The action of potassium on ammonia has been examined by Gay-Lussac and Thenard, and by Sir H. Davy. When the metal is heated in the gas, a fusible olive-coloured substance is obtained, of a crystallized fracture, translucent at the edges, heavier than water, and a non-conductor of electricity. It fuses at a little above 212°. It burns in oxygen, producing hydrated potassa and nitrogen: exposed to air, it slowly deliquesces, and evolves ammonia: water rapidly acts upon it, producing potassa and ammonia. The nature of this compound is not clearly understood: Gay-Lussac and Thenard consider it as a compound of nitrogen, potassium, and ammonia; for hydrogen is evolved during its production.

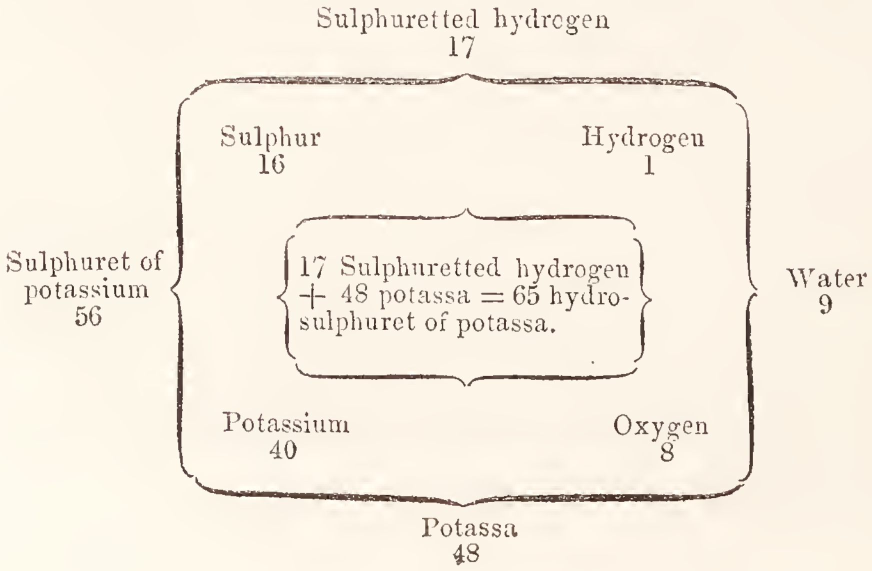
Potassium and Sulphur.—When potassium and sulphur are heated together in an exhausted tube, the sulphur not being in excess, intense action ensues, attended by the vivid combustion of the potassium, and a brownish grey compound results: when proper proportions of the materials are used, this appears to be a true *sulphuret of potassium*, consisting of

1 proportional of potassium . . . . = 40
1 ,, sulphur . . . . = 16

Equivalent of sulphuret of potassium . . . = 56

The same compound is obtained by passing hydrogen through a red-hot tube containing sulphate of potassa: water is formed in consequence of the deoxydizement, by the hydrogen, of the acid and of the potassa. Thus procured it is a dark reddish-brown substance, not very inflammable, and deliquescent.

When sulphuret of potassium is put into water it furnishes a colourless solution of *hydrosulphuret of potassa*, in consequence of the decomposition of one proportional of water, by one of the sulphuret, as shown in the following diagram:—



A similar hydrosulphuret of potassa may be obtained by passing sulphuretted hydrogen through an aqueous solution of potassa; the compound, therefore, may be considered as containing

1 proportional of potassa . . . . = 48
1 „ sulphuretted hydrogen . . . . = 17

Equivalent of hydrosulphuret of potassa . . = 65

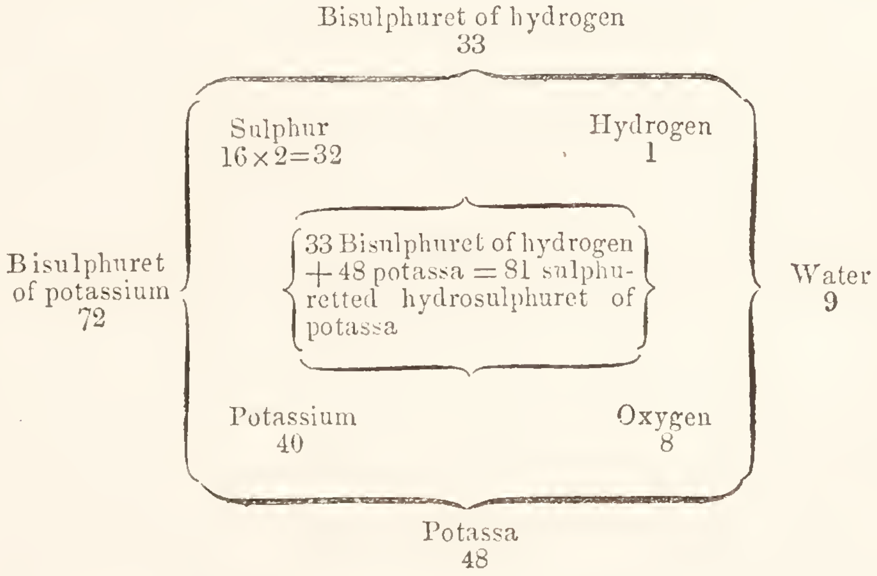
When dilute acids are dropped into a solution of this hydrosulphuret, sulphuretted hydrogen is evolved, and no potassa precipitated: when the solution is exposed to air, it absorbs oxygen, and becomes converted into one of hyposulphite of potassa.

Bisulphuret of Potassium.—When potassium is heated with excess of sulphur, a brown fusible substance is obtained, permanent at a red heat, and consisting of

1 proportional of potassium . . . . = 40
2 proportionals of sulphur (16 ×2) . . . . . . = 32

Equivalent of bisulphuret of potassium . . . = 72

Acting upon water this compound decomposes one proportional of that fluid, and forms a yellow solution of sulphuretted hydrosulphuret of potassa, or of a compound of potassa with bisulphuretted hydrogen, as in the following diagram.



This compound, therefore, consists of

1 proportional of potassa . . . . = 48
1 „ bisulphuretted hydrogen . . . = 33

Equivalent of sulphuretted hydrosulphuret of potassa = 81

The aqueous solution of this compound is of a yellow colour, and when the dilute acids are added to it, sulphuretted hydrogen is evolved and sulphur precipitated; but if a *strong* solution of the sulphuretted hydrosulphuret be poured into muriatic acid, a viscid substance falls, which is bisulphuretted hydrogen (see page 269). Exposed to air, this solution passes into a hyposulphite, and sulphur is deposited.

It appears that these are the only two definite compounds of sulphur and potassium just described, both of which are permanent at high temperatures, but these unite with sulphur by fusion at a moderate heat, apparently indefinitely, though some chemists have assumed that several definite combinations may be obtained. Berzelius, for instance, supposes that there are no less than seven definite sulphurets of potassium, in which one proportional of metal is combined respectively with 1, 2, 3, 3½, 4, 4½, and 5 proportionals of sulphur (*Ann. de Philos.*, *N. S.*, iv. 214), but his experiments do not seem to justify the conclusion.

Potassa and Sulphur.—When sulphur is fused with hydrate of potassa, the water of the hydrate evaporates, and the oxide of potassium is decomposed, giving rise, at a red heat, to sulphuret or bisulphuret of potassium (according to the quantity of sulphur used), and to hyposulphite (which becomes sulphate) of potassa.

When carbonate of potassa and sulphur are heated together, carbonic acid is evolved, and the potassa and the sulphur act upon each other as just described; the result being, if air be not carefully excluded, sulphuret of potassium and sulphate of potassa.

The compounds thus obtained, by fusing potassa, or its carbonate with sulphur, were formerly designated *Livers of Sulphur*, in consequence of their colour; and the conversion of sulphate of potassa into liver of sulphur by the action of charcoal and heat, was an experiment instituted by Stahl in support of the phlogistic hypothesis. Exposed to air, these sulphurets deliquesce, and exhale a disagreeable smell: their taste is bitter, acrid, and nauseous. The general results of dissolving them in water, by which hydrosulphurets of potassa are obtained, have been above noticed. When the colourless solution, obtained by passing sulphuretted hydrogen through a solution of potassa, is cautiously evaporated out of the contact of air, it furnishes prismatic crystals of a bitter, acrid taste, which deliquesce in the air.

When sulphur is boiled with the hydrosulphuret, or when excess of sulphur is boiled in solution of potassa, bihydrosulphuret of potassa may be obtained ; but as this compound, when in solution, dissolves variable and apparently indefinite portions of sulphur, an uniform combination is not in this way easily obtainable.

When sulphur and the alkalies are fused together at a high temperature, the latter undergo decomposition, and sulphurets of their metallic bases are actually formed.—VAUQUELIN, *Ann. de Chim. et Phys.* vi. 22.

Hyposulphite of Potassa is formed by decomposing hydrosulphuret of potassa by sulphurous acid and evaporating to a pellicle, when it forms acicular crystals, of a cooling, bitter taste, and deliquescent. After careful drying it takes fire upon elevating the temperature, and burns like tinder. Its solution readily dissolves moist chloride of silver ; and when exposed to air becomes sulphite, and ultimately sulphate, of potassa. This salt is also formed when the alcoholic solution of sulphuret of potassium is exposed to air. The adhering sulphuret may be washed from its crystals by alcohol.

Sulphite of Potassa is formed by passing sulphurous acid into a solution of potassa, or of its carbonate, and evaporating out of the contact of air. Rhomboidal plates are obtained, white, of a sulphurous taste, and very soluble. By exposure to air, they pass into sulphate of potassa. Berzelius observes, that there is a bisulphite of potassa, more easily crystallizable than the sulphite, and generally confounded with it.

Sulphate of Potassa is the result of several chemical operations carried on upon a large scale in the processes of the arts. It may be formed directly by saturating sulphuric acid by potassa. It is the *sal de duobus* of the old chemists : the *potassæ sulphas* of the *London Pharmacopæia.* Its taste is bitter. It crystallizes in short six-sided prisms, terminated by six-sided pyramids. The body of the prism is often wanting, and the triangular-faced dodecaëdron results. These forms have been particularly described by Mr. Levy, *Quarterly Journal*, xv. 285. The crystals, whilst forming, sometimes emit a yellow light. This salt dissolves in 16 parts of cold, and 5 of boiling water; and in consequence of its difficult solubility, it is thrown down in a white granular powder, when sulphuric acid is added to a moderately strong solution of potassa. It is insoluble in alcohol. Exposed to a red heat, it decrepitates and melts, but is not decomposed. At very high temperatures it is volatilized. It is decomposed at a red heat by hydrogen, which carries away the oxygen both of the acid and of the potassa, and converts it into sulphuret of potassium. When fused with sulphur, this salt undergoes no change; the sulphur sublimes unaltered. (Vauquelin, *Ann. de Chim. et Phys.* v. 20.) Intensely heated with one-fifth its weight of powdered charcoal, it produces sulphuret of potassium. When about 2 parts of sulphate of potassa and 1 of lamp-black, intimately mixed in fine powder, are heated to redness in a coated phial, and great care taken to exclude the air during cooling, a compound is obtained which takes fire upon exposure to air. It appears to contain a compound of potassium, which powerfully attracts oxygen, and thus excites heat enough to inflame the charcoal and sulphur. Gay-Lussac attributes the combustibility of common pyrophorus (see ALUMINA) to the presence of this compound.

Sulphate of potassa contains no water of crystallization, and consists of

1 proportional of sulphuric acid . . .	=	40 ..	45.5
1 „ potassa	=	48 ..	54.5
Equivalent of sulphate of potassa .	=	88	100.

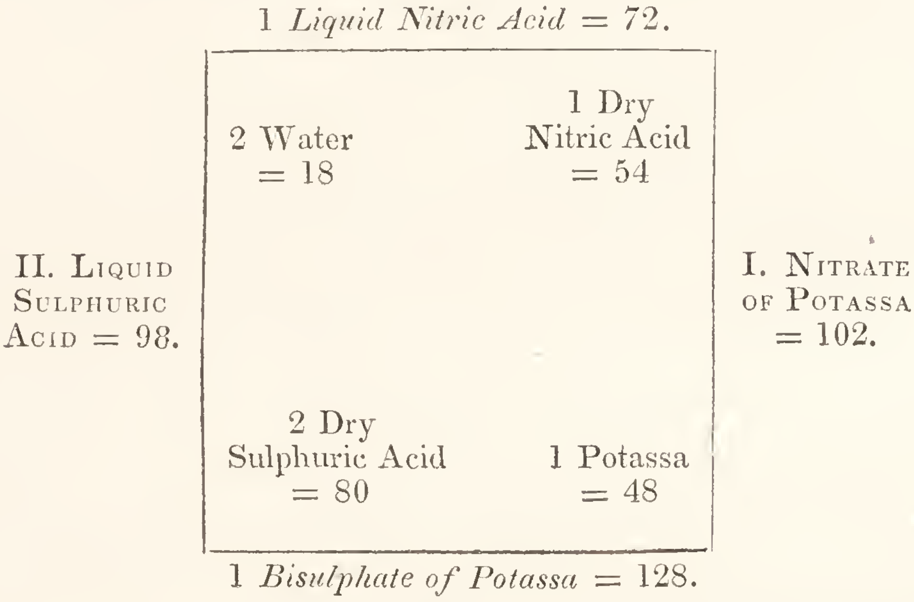
The *Bisulphate* or *Supersulphate of Potassa* is formed by adding sulphuric acid to a hot solution of sulphate of potassa, or by boiling sulphate of potassa with half its weight of sulphuric acid in a platinum crucible, till none of the acid escapes when the heat approaches redness: the saline mass, dissolved and evaporated, furnishes crystals which affect various forms dependent upon the circumstances under which they are obtained: sometimes they present an acicular mass; at other times they are tabular, and sometimes flattened prisms. Those crystals which form in delicate needles, are soluble in 2 parts of water at 60°, and consist of

2 proportionals of sulphuric acid . .	=	80 ..	62.5
1 „ potassa	=	48 ..	37.5
		128	100.

By a continued red heat this salt loses its excess of acid. Alcohol added to its aqueous solution throws down neutral sulphate of potassa.

Bisulphate of potassa is also formed in the distillation of equal parts of nitre and sulphuric acid: nitric acid passes over, and a residuary bisulphate of potassa is produced, commonly known under the name of *sal enixum*. It is the *arcanum duplicatum*, or *panacea Holsatica* of old pharmaceutists. It is used for cleansing coin and other works in metal; and has a place in the *London Pharmacopœia*.

The following diagram will illustrate the formation of this salt, and of liquid nitric acid, in the distillation of two proportionals of sulphuric acid with one of nitre:—



Sesquisulphate of Potassa.—This salt has been described and analyzed by Mr. Phillips: he obtained it as the residue of the distillation of equal weights of nitre and sulphuric acid (sp. gr. 1.8442). It was in filamentous crystals, and consisted of

3 atoms of sulphuric acid	=	120
2 „ potassa	=	96
1 „ water	=	9
		225

Philos. Mag. N. S. ii. 429.

Hyposulphate of Potassa is obtained by decomposing a solution of hyposulphate of baryta by sulphate of potassa. It forms permanent crystals of a bitter taste, difficultly soluble in cold, but readily so in hot water. It is anhydrous. Its crystals are described by Mr. Levy in the *Quarterly Journal* (xv. 285).

Ammonio-Sulphate of Potassa is a triple salt, formed by adding ammonia to bisulphate of potassa. It crystallizes in brilliant plates of a bitter taste.—Link, *Crell's Annals,* 1796.

Phosphuret of Potassium is a chocolate-brown compound, which rapidly decomposes water, producing phosphuretted hydrogen gas, and hydrophosphuret of potassa. It is formed by cautiously heating potassium with phosphorus out of the contact of air. It consists of 12 phosphorus + 40 potassium = 52.

When heated with potassium it appears capable of combining with an additional proportion of that substance, and forms a lead-coloured compound, in which it appears probable that 2 proportionals of potassium are combined with 1 of phosphorus.

Hypophosphite of Potassa has been examined by Dulong. It is very deliquescent, and soluble in water and alcohol nearly in all proportions. When heated it evolves phosphuretted hydrogen and phosphorus, and is converted into phosphate of potassa.—*Ann. de Chim. et Phys.*, ii. 142. It is best prepared by mixing a solution of hypophosphite of lime with one of carbonate of potassa, filtering, and evaporating to dryness: alcohol, digested upon the residue, takes up the hypophosphite of potassa: it is uncrystallizable, but may be dried in vacuo (Rose, *Quarterly Journal,* iv. 206).

Phosphite of Potassa is a soluble deliquescent uncrystallizable salt, not hitherto accurately examined.

Phosphate of Potassa is a soluble difficultly crystallizable salt. It is insoluble in alcohol. It may be obtained by careful evaporation, in four-sided prisms, and octoëdrons. It contains

1 proportional of potassa	. . . .	= 48
1 ,, phosphoric acid	. . . .	= 28
		76

Subphosphate of Potassa.—When phosphate of potassa is fused in a platinum crucible with potassa, it is converted into subphosphate of potassa, which is nearly insoluble in cold, and very difficultly soluble in hot water. It is fusible before the blowpipe, yielding a globule, opaque when cold, but transparent whilst in fusion. The theoretical composition of this salt is

2 proportionals of potassa	. . . .	= 96
1 „ acid	. . . .	= 28

Superphosphate or *Biphosphate of Potassa* is formed by dissolving the neutral phosphate in phosphoric acid and evaporating till crystals are obtained, which are prismatic and very soluble in water, but insoluble in alcohol.

Potassium and Selenium.—When these substances are heated together, they combine with intense action, and produce a grey crystalline compound, forming a deep brown solution with water, from which acids evolve seleniuretted hydrogen and precipitate selenium. When selenium is heated with excess of potassium, an explosion ensues, and a compound is obtained which furnishes a red solution, and evolves hydrogen by the action of water. The odour and general characters of these compounds so much resemble those with sulphur, as not easily to be distinguished except by the brown and red colours of their solutions.

When powdered selenium is boiled in solution of potassa, a dark brown solution of an hepatic taste and smell is the result, from which acids precipitate selenium. Fused with potassa, selenium produces seleniate of potassa and seleniuret of potassium.

Selenious Acid and *Potassa* form, according to Berzelius, a neutral *selenite of potassa*, a *biselenite*, and a *quadriselenite*. The first is difficultly crystallisable, somewhat deliquescent, and insoluble in alcohol. The second forms plumose crystals, very sparingly soluble in alcohol. The third is uncrystallisable.

Seleniate of Potassa.—This salt may be obtained by fusing nitre with selenium or selenious acid, or by saturating the selenic acid by potassa. From the statement of Mitscherlich it consists of

1 proportional of potassa	. . .	= 48
1 „ selenic acid	. . . .	= 64
Equivalent of Seleniate of Potassa	.	= 112

According to the same authority, the seleniates and the sulphates are isomorphous.—*Ann. de Ch. et Ph.*, xxxvi. 104.

Potassium and Carbon.—When potassa is decomposed at high temperatures by carbon, a black substance remains in the retort, which is probably a *carburet of potassium.* It takes fire upon water; and if plunged into that fluid evolves carburetted hydrogen.

Potassa and Carbonic Acid.—These bodies combine in two proportions, forming the *carbonate* and the *bicarbonate* of potassa, compounds which have been long used and known under various names—such as *fixed nitre, salt of tartar, salt of wormwood, vegetable alkali,* &c. Their composition was first ascertained by Black. Bergman, in 1774, described their most essential properties.—*Opuscula,* vol. i. p. 13.

Carbonate of Potassa is a salt of great importance in many arts and manufactures, and is known in commerce in different states of purity, under the names of *wood-ash, pot-ash,* and *pearl-ash.* It is the *subcarbonate of potassa* of the *London Pharmacopœia.*

It may be obtained directly by passing carbonic acid into a solution of potassa, till saturated, evaporating to dryness, and exposing the dry mass to a red heat; or indirectly by burning *tartar,* lixiviating the residue, and evaporating to dryness, whence the name *salt of tartar* has been applied to it.

This salt is fusible without decomposition, at a red heat; it is very soluble in water, which at 55° takes up about its own weight; it deliquesces by exposure to air, forming a dense solution, once called *oil of tartar per deliquium.* Its taste is alkaline, and it renders vegetable blues green. It consists of

1 proportional of potassa . . .	= 48....	68.5
1 „ carbonic acid . .	= 22....	31.5
Equivalent of carbonate of potassa .	= 70	100

The great consumption of this article in various manufactures is exclusively supplied by the combustion of vegetables, and consequently its production is almost limited to those countries which require clearing of timber, or where there are vast natural forests. The English market is chiefly supplied from North America. If any vegetable growing in a soil not impregnated with sea-salt be burned, its ashes will be found alkaline from the presence of carbonate of potassa. If the ashes be submitted to heat, so as to burn away the carbonaceous matter entirely, they become a white mass, generally termed *pearl-ash.*

The pearl-ash of commerce contains a variety of impurities, which render it of variable value. In general, its purity may be judged of by its easy solubility in water, two parts of which should entirely and easily dissolve one part of the salt without the aid of heat; the residue, if any, consists of impurities. The quantity of nitric acid of a given density, requisite to saturate a given weight, may also be resorted to as a criterion of its purity. 100 parts of nitric acid, specific gravity 1.36, will saturate 65.7 parts of dry carbonate of potassa, which are equivalent to 45 parts of pure potassa; or, 355 grains of diluted sulphuric acid of the specific gravity 1.141 exactly neutralise 100 grains of pure carbonate of potassa. Hence, if we dissolve 100 grains of the alkali to be examined in six or eight parts of water, and gradually add the test sulphuric acid till we find, by the application of violet or mallow paper, that the alkali is exactly neutralized, we may deduce, from the weight of the acid consumed, the proportion of real carbonate present: for as 355 is to 100, so is the weight of the test acid employed to that of the pure carbonated alkali present. To save trouble, the acid properly diluted may be put into a glass tube, so graduated as to show directly the value of the alkali by the quantity consumed in its saturation. Thus we find, by reference to the scale of equivalents, that 100 parts of carbonate of potassa are saturated by 70 of sulphuric acid, specific gravity 1.85. If, therefore, we put 70 grains of such acid into a tube divided into 100 parts, and fill it up with water, it follows that the quantity of carbonate of potassa existing in any sample of pearl-ash under examination will be directly shown by the measure of such diluted acid required for saturation—100 grains of the sample, if pure carbonate, would require the whole 100 measures of acid: but if only containing 50 *per cent.* of pure carbonate, the 100 grains would be saturated by 50 measures of the test acid, and so on. Such graduated tubes are sometimes called *alkalimeters.*

The common mode of purifying pearl-ash consists in pouring upon it its weight of cold water, and stirring the mixture occasionally during twenty-four hours; the solution is then poured clear off the residuary salt, and evaporated to dryness. In this way much impurity is separated, the foreign salts being, with few exceptions, much less soluble than the alkaline; yet some of them are taken up, and the silicated potassa which rough pearl-ash always contains, is also dissolved. The carbonate from tartar is more pure, but often contains lime. The purest carbonate is undoubtedly that obtained by exposing the bicarbonate to heat sufficient to expel its water and half of its carbonic acid; the salt is then dissolved in water, which generally leaves some silica, that has been rendered insoluble by the exposure to heat. If the salt be fused, this silica combines with the potassa and expels a portion of carbonic acid, so that although a certain degree of heat is required to drive off the excess of carbonic acid, and render the silica insoluble, too much heat causes it again to be taken up, and rendered soluble in water. With these precautions, upon evaporating the solution to dryness in a silver basin, a very pure carbonate of potassa is obtained. Carbonate of potassa is also obtained when two parts of powdered tartar (bitartrate of potassa) and one of nitrate of potassa, thoroughly mixed, are deflagrated in successive portions in an iron ladle or crucible. The residue (often called *black flux*) is lixiviated and evaporated as usual. Equal parts of nitre and tartar, treated in the same way, furnish *white flux*, in which the whole of the charcoal is destroyed by combustion. These fluxes are of much use in certain metallurgical operations, contributing to the fusibility of refractory earthy compounds.

A saturated solution of carbonate of potassa in water contains about 48 per cent. of the salt, and has a specific gravity of 1.5. If it be evaporated till of a specific gravity of 1.62 whilst warm, and then poured into a tall cylindrical glass vessel, and suffered slowly to cool, it furnishes crystals in long rhomboidal tables, which are very deliquescent.

Carbonate of potassa is insoluble in alcohol, and is occasionally employed to deprive alcohol of water. Berzelius states, that if steam be passed over this salt in a red hot tube, its carbonic acid is expelled, and hydrated potassa formed. A few of the metals, and charcoal at very high temperatures, decompose it with the production of potassium. The action of sulphur and of phosphorus upon this carbonate has already been noticed.

Bicarbonate of Potassa is formed by passing a current of carbonic acid into a solution of the carbonate. By evaporation at a very moderate heat, crystals are obtained in the form of four-sided prisms, with dihedral summits. They are not deliquescent. Their primitive form and cleavage have been described by Mr. Levy in the *Quarterly Journal*, xv. 286. Their taste is only slightly alkaline, and they require for solution four parts of water, at 60°. Boiling water dissolves nearly its own weight of the crystals, but during the solution a portion of carbonic acid is evolved. Exposed to a red heat, they evolve carbonic acid and water, and carbonate of potassa remains. This salt was first observed by Dr. Wollaston to contain exactly twice the quantity of carbonic acid existing in the carbonate (*Phil. Trans.* 1808); hence, in its anhydrous state it consists of

2 proportionals of carbonic acid . .	(22×2)	= 44
1 „ potassa		= 48
Equivalent of anhydrous bicarbonate of potassa .		= 92

In its crystalline form it contains, according to Berard, 9 per cent. of water. Crystallized bicarbonate of potassa, therefore, consists of

1 proportional dry bicarbonate	= 92
1 „ water	= 9
	101

It is generally stated that during the saturation of carbonate of potassa with carbonic acid, the whole of the silica is precipitated; but this is not the case; and it will be found that during the crystallization of the salt, an additional deposition of silica ensues. When the crystals of bicarbonate have been redissolved, and a second time crystallized, the whole of the silica is excluded.

In the *London Pharmacopœia*, the more expensive method of obtaining this salt by the action of carbonate of ammonia on carbonate of potassa is resorted to.

The following proportions may be used for the preparation of bicarbonate of potassa upon the large scale: 100 lbs. of purified carbonate of potassa are dissolved in 17 gallons of water, which, when saturated with carbonic acid, yield from 35 to 40 lbs. of crystallized bicarbonate; 50 lbs. of carbonate of potassa are then added to the mother liquor, with a sufficient quantity of water to make up 17 gallons, and the operation repeated.

The carbonate and bicarbonate of potassa are both decomposed by lime, which deprives them of carbonic acid; hence the use of that earth in the process for obtaining pure *potassa.* They are also decomposed by the greater number of acids, which unite with the alkali, the carbonic acid being expelled with effervescence.

Sesquicarbonate of Potassa.—When the solution of the bicarbonate is boiled until carbonic acid no longer escapes, it loses one-fourth of its acid, and, on cooling, forms deliquescent crystals, insoluble in alcohol. The same salt is obtained by dissolving 100 parts of carbonate and 131 of bicarbonate of potassa in water. This salt was first mentioned by Berthollet in 1809 (Berzelius). It is probably identical with that noticed by Dr. Thomson (*Princip. of Chem.*, ii. 225), who states it to consist of

1 proportional of	potassa	= 48
1½ „	carbonic acid	= 33
6 „	water (9 × 6)	= 54
		135

Potassium and Cyanogen.—Potassium heated in cyanogen absorbs the gas, and produces a yellowish grey *cyanuret of potassium,* which, by the action of water, becomes *hydrocyanate of potassa.* This salt speedily decomposes, and becomes converted into carbonic acid and ammonia. When cyanogen is passed into a solution of potassa, a liquid is obtained which, when the cyanogen is in excess, is brown and smells of the gas. This compound has been called cyanuret or cyanide of potassa.

Sulphocyanuret of Potassium and Sulphocyanate of Potassa.—When equal parts of ferrocyanate of potassa (see Iron) and of sulphur are well mixed in fine powder and exposed to nearly a red heat, the mixture fuses and takes fire; it should be stirred as long as it continues to burn, and kept for a few minutes in fusion. The residue, digested in hot water and filtered, furnishes a solution of sulphocyanate of potassa, which, evaporated to dryness, affords *sulphocyanuret of potassium*; sulphuret of iron remains upon the filter. The solution, when concentrated by evaporation, yields crystals which are very deliquescent, and which, according to Dr. Turner, neither contain water nor its elements, but are a pure sulphocyanuret. In form, taste, and fusibility they are very analogous to nitre. They consist of

1 proportional of potassium	. . .	= 40
2 „ sulphur (16 × 2)	. .	= 32
1 „ cyanogen	. . .	= 26
Equivalent of sulphocyanuret of potassium		= 98

And the sulphocyanate of potassa is composed of

1 proportional of potassa	. . .	= 48
1 „ sulphocyanic acid	. .	= 59
Equivalent of sulphocyanate of potassa		= 107

Seleniocyanate of Potassa.—Berzelius formed this salt by heating a mixture of ferrocyanate of potassa and selenium, and washing the fused mixture. By evaporation, anhydrous crystals, probably of *seleniocyanuret of potassium*, were obtained.

Borate of Potassa is a salt which has been scarcely examined : it may be prepared by boiling boracic acid in solution of potassa, or by exposing a mixture of boracic acid and nitre to a bright red heat ; it furnishes by solution and evaporation quadrangular prisms, permanent in the air.

Fluoborate of Potassa is obtained, according to Berzelius, by adding fluoboric acid to a solution of fluoride of potassium: a gelatinous precipitate ensues, which, collected upon a filter, becomes opaque, and feels, whilst moist, like powdered starch. When dry, it has a bitterish taste, and reddens litmus. 100 parts of cold water only dissolve 1.5 of this salt ; but it is more soluble in boiling water, and, as the solution cools, it deposits it in small anhydrous crystals.

The salts of potassium are soluble in water, and afford no precipitates with pure or carbonated alkalis. They produce a precipitate in muriate of platinum, which is a triple compound of potassa, oxide of platinum, and muriatic acid. They are not changed by sulphuretted hydrogen, nor by ferrocyanate of potassa. Added to sulphate of alumina, they enable it to crystallize, so as to form alum.

Section II. Sodium.

Sodium, discovered by Sir H. Davy in 1808, is obtained from soda, by an operation analogous to that for procuring potassium from potassa, by the gun-barrel; but the hydrate of soda is more difficult of decomposition than that of potassa, and the product of metal less certain and abundant: it may be facilitated, according to Thenard, by fusing the soda with a small proportion of potassa; so that an alloy of sodium and potassium distils over, which may be decomposed by keeping it in an open vessel in oil of turpentine; the potassium combines with the oil, and the sodium remains pure and metallic. It is soft, malleable, and easily sectile, and does not, like potassium, become brittle at 32°, but even at that low temperature several globules may be welded together by pressure. Its specific gravity is 0.97. In colour it resembles lead, but instantly tarnishes on exposure to air. It fuses at about 190°, and is volatile at a white heat. It burns when heated in contact with air, and requires the same cautions to preserve it as potassium.

Sodium and Oxygen.—When sodium is thrown upon water, it produces violent action, but the metal does not in general inflame, unless the quantity of water be very small; hydrogen is evolved, and a solution of soda is procured. By the quantity of hydrogen evolved, we learn that *soda* (*protoxide of sodium*) consists of about 74.6 sodium, and 25.4 oxygen *per cent.*; and, if it be considered as the protoxide, the number representing the metal will be 24, and anhydrous soda will consist of

1 proportional of sodium . . . . = 24
1 „ oxygen . . . = 8

Equivalent of protoxide of sodium or soda . = 32

By heating sodium in oxygen, it burns vividly, and a yellowish-green *peroxide* is formed, which, by the action of water, evolves oxygen, and produces a solution of the protoxide. It is composed of

1 proportional of sodium . . . = 24
1½ „ oxygen . . . = 12

Equivalent of peroxide of sodium . . = 36

Soda, or Hydrate of Soda, as it usually occurs in the laboratories, is obtained from the carbonate, by the action of lime and alcohol, as described under the head *Potassa.* Its colour is grayish-white, and it requires a red heat for fusion. It has the same general characters as hydrate of potassa; like it, it retains water at a red heat, and is deprived of it by the same means. It consists of

1 proportional of anhydrous soda	. .	= 32
1 „ water	. . .	= 9
Equivalent of protohydrate of soda	. .	= 41

Like potassa, it may be obtained in crystals from its concentrated aqueous solution, containing a larger relative quantity of water.

The following Table by Dalton shows the proportion of anhydrous soda in solutions of different specific gravities:—

Specific grav. of solution.	Dry Soda per cent. by weight.	Boiling point.
1.85	63.6	600°
1.72	53.8	400
1.63	46.6	300
1.56	41.2	280
1.50	36.8	265
1.47	34.0	255
1.44	31.0	248
1.40	29.0	242
1.36	26.0	235
1.32	23.0	228
1.29	19.0	224
1.23	16.0	220
1.18	13.0	217
1.12	9.0	214
1.06	4.7	213

Soda is distinguished from potassa, by forming an *efflorescent* paste when exposed to the atmosphere; potassa, under the same circumstances, *deliquesces.* If excess of tartaric acid be added to a solution of soda, there is no precipitation; but in solution of potassa it occasions a deposit of a number of minute crystals. Solution of soda occasions no precipitate when added to solution of muriate of platinum. Solution of potassa occasions a yellow precipitate in solution of platinum. In combination with acids it produces a perfectly distinct class of salts.

Chloride of Sodium.—Sodium, when heated in chlorine, burns and produces a white compound, of a pure saline flavour. It has all the properties of *common salt* or *muriate of soda*, and consists of

1 proportional of chlorine . . . = 36
1 „ sodium . . . = 24
Equivalent of chloride of sodium . . = 60

This compound is decomposed when heated with potassium: sodium and chloride of potassium are the results.

When soda is heated in chlorine, oxygen is evolved; when heated in muriatic acid gas, water is formed; and in both cases chloride of sodium is the product.

Common salt exists abundantly in nature both as a solid fossil and dissolved in spring water and in the ocean. Immense masses of it are found in Cheshire, where it is known under the name of *rock salt.*

When heated, chloride of sodium falls into pieces with a crackling noise, or *decrepitates.* At a red heat it fuses without undergoing any decomposition, and on cooling concretes into a hard white mass; at a bright red heat it slowly sublimes, and tinges flame of a beautiful blue colour. It is very nearly insoluble in alcohol. In the solubility of common salt there is this peculiarity, that it is taken up nearly in the same proportion by cold and by hot water; so that, although its solution deposits crystals during evaporation, it does not do so by cooling. According to Berzelius, 1 part of salt dissolves in $2\frac{14}{17}$ of water at 60°, and in $2\frac{13}{17}$ of water at 212°. According to Gay-Lussac, 100 parts of water at 58° dissolve 36 of salt; at 140°, 37 parts; and at 225°, which is the boiling point of a saturated solution, 100 parts of water dissolve 40.38. At 32° water dissolves rather more than at 60°. When pure, it does not alter by exposure to air, though generally more or less deliquescent, from containing chlorides of magnesium and of calcium: obtained by slow or spontaneous evaporation, it crystallizes in solid cubes; but when procured, as is usually the case, at a boiling heat, by removing its crystals from the surface of its solution whilst evaporating, it exhibits the form of a hollow quadrangular pyramid. These crystals are all anhydrous, though they often include a little interstitial water. A concise account of the different methods of manufacturing salt will be found in Aikin's *Dictionary*, Art. Muriate of Soda. Dr. Henry states (*Phil. Trans.* 1810) that the various forms under which salt is known in commerce, such as *bay-salt*, *fishery-salt*, &c., arise from modifications in the size and hardness of the grain, and not from any essential difference of composition. The following table includes his general results:—

	Kind of Salt.	1000 Parts by Weight consist of								
		Insoluble Matter.	Muriate of Lime.	Muriate of Magnesia.	Total Earthy Muriates.	Sulph. of Lime.	Sulph. of Magnesia.	Total Sulphates.	Total Muriates.	Pure Muriate of Soda.
For. Bay Salt.	St. Ube's . .	9	trace	3	3	23½	4½	28	40	960
	St. Martin's .	12	do.	3½	3½	19	6	25	40½	959½
	Oleron . .	10	do.	2	2	19½	4½	23¾	35¾	964¼
Brit. Salt. fr. Sea-water.	Scotch (common)	4	—	28	28	15	17½	32½	64½	935½
	Scotch (Sunday)	1	—	11½	11½	12	4½	16½	29	971
	Lymington (com.)	2	—	11	11	15	35	50	63	937
	Ditto (cat) .	1	—	5	5	1	5	6	12	988
Cheshire Salt.	Crushed rock .	10	0.1⁄16	0.3⁄16	0.¼	6½	—	6½	16¾	983¼
	Fishery . . .	1	0.¼	0.¾	1	11¼	—	11¼	13¼	986¾
	Common . .	1	0.¼	0.¾	1	14½	—	14½	16½	983½
	Stoved . .	1	0.¼	0.¾	1	15½	—	15½	17½	982½

Chloride of sodium is decomposed by moist carbonate of potassa, and chloride of potassium and carbonate of soda are the results. (Westrumb in English translation of *Crell's Journal*, ii. 127.) In the common process for obtaining muriatic acid it is decomposed by sulphuric acid. In this decomposition there is a transfer of the oxygen contained in the water of the sulphuric acid to the sodium of the salt, the chlorine of which combines with the hydrogen of the water to produce muriatic acid gas. The oxide of sodium unites with the dry sulphuric acid to produce sulphate of soda. (See diagram, p. 425.) It is also decomposed by nitric acid.

Common salt is of most extensive use as a preservative of food, and as a condiment, as a source of soda and of muriatic acid and chlorine, and for various agricultural and horticultural purposes. (*Quarterly Journal*, x. 52.) Glauber first obtained muriatic acid from it, and the existence of soda in it was first shown by Duhamel.

Chlorate of Soda was procured by Mr. Chenevix (*Phil. Trans.* 1802), by the same process as chlorate of potassa, but not possessing less solubility than chloride of sodium, the two substances are difficultly separable. Vauquelin obtained it by saturating chloric acid with soda. Its crystals resemble those of chlorate of potassa, its taste is also nearly similar. It dissolves in three parts of cold water, and in somewhat less at 212°. It is more soluble in alcohol than chloride of sodium; hence that solvent is sometimes used to separate the two compounds. It is slightly deliquescent in very damp weather.

Sodium and Iodine act upon each other with the same phenomena as potassium, and an *iodide of sodium* is obtained. The hydriodic acid and soda produce a deliquescent salt, which crystallizes in flat rhomboidal prisms; when heated it fuses, and loses its water of crystallization. The residue is iodide of sodium. When intensely heated it becomes slightly alkaline, and is volatilized. 100 parts of water at 60° dissolve 173 of this iodide. It is also soluble in alcohol.

Iodate of Soda is made by dissolving iodine in solution of soda; a white compound forms, which is the iodate with a portion of iodide of sodium; the latter may be removed by alcohol, which does not dissolve the iodate. 100 parts of water at 60° dissolve 7.3 of this salt. It forms small prismatic tufted crystals, which, when heated, afford oxygen and iodide of sodium.—Gay-Lussac, *Ann. de Chim.*, xci.

Sodium and Bromine act upon each other with much intensity, and the resulting *bromide of sodium* is a fusible compound, soluble in water. When bromine acts upon solution of soda, bromide of sodium and *bromate of soda* are the results. These compounds have scarcely been examined.

Sodium and Fluorine.—Fluoride of Sodium is obtained by saturating hydrofluoric acid with soda, and evaporating to dryness; a white and difficultly fusible compound results, the aqueous solution of which, when pure, furnishes cubical crystals, and acts upon glass. 100 parts of water dissolve 4 of this fluoride, and it is not more soluble in hot than in cold water.

No combination has yet been discovered of sodium and hydrogen.

Nitrate of Soda.—The *cubic nitre* of old writers. This salt crystallizes in rhombs, soluble in 3 parts of water at 60°, and in less than its weight at 212°*. It has a cool sharp flavour, and is somewhat deliquescent, and therefore unfit for the manufacture of gunpowder. It is often found in crude nitre, resulting apparently from the decomposition of common salt. Large quantities of *native nitrate of soda* have been discovered in Peru, forming a stratum covered with clay and alluvium of many miles in extent. It is an anhydrous salt, composed of

1 proportional of soda . . . . = 32
1 ,, nitric acid . . . = 54

Equivalent of nitrate of soda . . . = 86

It has occasionally been imported into this country from Valparaiso, but has not become an article of regular commerce; and although unfit, in consequence of its deliquescent tendency, for the manufacture of gunpowder, it might be advantageously employed in most fireworks, and used also as a substitute for nitre (it being probably cheaper) in the manufacture of nitric acid, of sulphuric acid, and other cases in which large quantities of nitre are consumed. It is probably too expensive as a source of soda.

The *nitrite of soda* has not been examined. It may be obtained as the corresponding salt of potassa. It is stated by Berzelius, that there are combinations of soda with nitrous and nitric oxides.

When *sodium is heated in ammonia*, hydrogen is disengaged, and an olive-coloured fusible substance formed, composed, according to Gay-Lussac and Thenard, of 100 sodium + 11.7 nitrogen. No analogous substance can be obtained by heating potassium in pure nitrogen gas.

Sodium and Sulphur.—The account of the action of sulphur on potassium and potassa, and of sulphuretted hydrogen

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* This is the usual statement in chemical works, but nitrate of soda is certainly more soluble. Berzelius says that one part dissolves in two of water at 60°, and Gay-Lussac (*Cours de Chimie*, Paris, 1828) asserts, that 100 parts of water at 32°, dissolve 73 parts; and at 212°, 173 parts. The experiments on the solubility of salts stand much in need of a general revision.

upon solution of the alkali, applies generally to sodium and soda, and their corresponding compounds.

The *sulphuret of sodium* consists of

1 proportional of sodium	. . .	= 24
1 ,, sulphur	. . .	= 16
Equivalent of sulphuret of sodium	.	= 40

The *bisulphuret of sodium*, and the *hydrosulphurets of soda*, are similarly constituted to those compounds of potassium.

The hydrosulphurets of soda derive some additional interest as being produced, upon the large scale, in some of the processes for obtaining soda by the decomposition of the sulphate of soda, as will presently be stated.

Hyposulphite of Soda is formed as hyposulphite of potassa. It is crystallizable in transparent four-sided prisms, deliquescent, of an intensely bitter taste, and insoluble in alcohol. Its aqueous solution readily dissolves moist chloride of silver. When heated, it fuses, then dries, and afterwards takes fire.

Sulphite of Soda is crystallizable in transparent four and six-sided prisms, soluble in four parts of water at 60°. It consists of 32 soda + 32 sulphurous acid = 64. The crystals contain twelve proportionals of water = 108. There is also a crystallizable *bisulphite of soda.*

Hyposulphate of Soda seems not to have been examined.

Sulphate of Soda—Glauber's Salt—Sal Mirabile—is abundantly produced in the manufacture of muriatic acid, by the action of sulphuric acid upon common salt. Common salt consists of 24 sodium + 36 chlorine. Sulphuric acid consists of 40 dry acid + 9 water. The water of the acid, consisting of 1 hydrogen + 8 oxygen, is decomposed. Its hydrogen is transferred to the chlorine to produce gaseous muriatic acid (1 H. + 36 C. = 37 Mur. A.), and its oxygen unites to the sodium, forming dry soda (8 Ox. + 24 S. = 32 soda). The 40 dry acid unite to the 32 soda, to produce sulphate of soda, which will be represented by the number 72.

This decomposition is perhaps more clearly shown in the following diagram *:—

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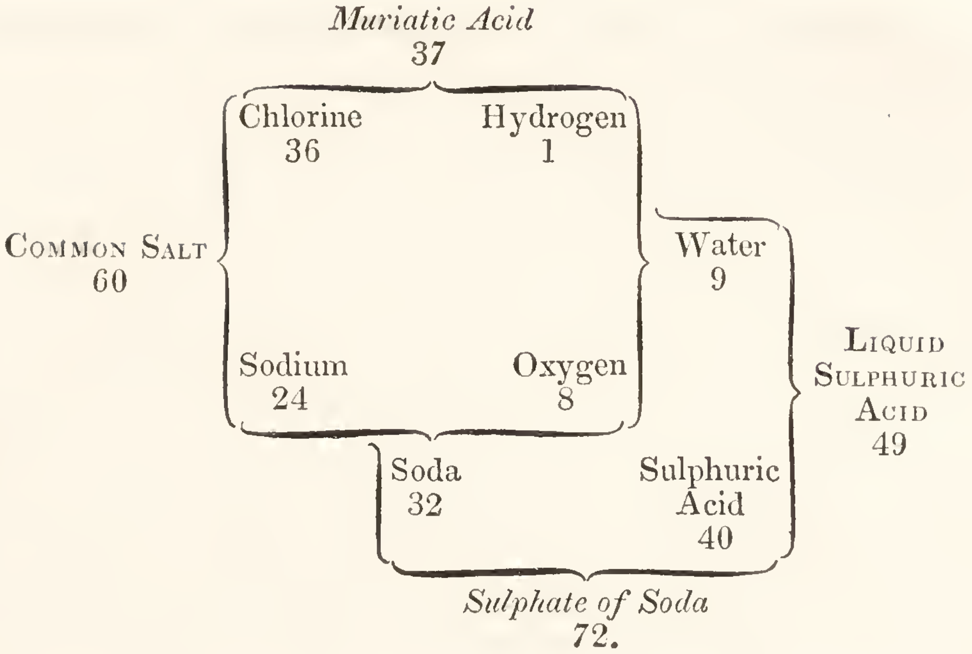
* The original substances are printed in capitals, the products in italics, and the components in common type.



Sulphate of soda crystallizes from its aqueous solution in large four-sided prisms, transparent, and efflorescent when exposed to air. Exposed to dry air, the crystals part with about 50 per cent. of water.

The anhydrous salt is composed of

1	proportional of soda . . .	=	32
1	„ sulphuric acid . .	=	40
		=	72

And the crystals consist of

1	proportional of anhydrous sulphate .		=	72
10	proportionals of water .	(9 × 10)	=	90
				162

The taste of sulphate of soda is saline and bitter: it is soluble in rather less than three times its weight of water at 60°. The solubility of sulphate of soda follows a singular law, first observed by Gay-Lussac. (*Ann. de Chim. et Phys.*, xi.) After having increased rapidly to about the temperature of 92°, where it is at its maximum, it diminishes to 215°, and at that temperature the salt is nearly of the same solubility as at 87°. It is insoluble in alcohol. When this salt is dissolved in its weight of boiling water, and a flask filled with it and tightly corked up, no crystallization generally ensues; but upon opening the flask it either immediately crystallizes, or does so upon touching the solution with a solid body. This experiment has already been referred to (pp. 5, 6). It sometimes, however, happens that a portion of the salt does crystallize, forming quadrangular crystals, which become opaque on exposure, and which, for sulphate of soda, are peculiarly hard; Mr. Faraday found these composed of

1 proportional of sulphate of soda . . = 72
8 proportionals of water . . (9 × 8) = 72
144

When exposed to heat, sulphate of soda undergoes watery fusion, that is, it melts in its water of crystallization, and a portion of anhydrous salt is deposited; when the water has evaporated, the residue may be raised to a high heat, without undergoing decomposition. The salt which has thus been deprived of its water by heat has an acrid taste, and produces a sense of heat upon the tongue in consequence of its absorbing water, which it does with great avidity.

Gay-Lussac obtained a powerful pyrophorus, by igniting a mixture of lamp-black and dry sulphate of soda, analogous to that mentioned under *Sulphate of Potassa.* (*Quarterly Journal*, iv. 208.)

Sulphate of soda is sometimes decomposed for the purpose of obtaining soda, by igniting it with chalk and charcoal, or with iron and charcoal, and various economical means have been proposed for obtaining sulphate of soda for the purpose: such as calcining a mixture of common salt, sulphate of lime, and charcoal; or by roasting in a proper furnace 100 parts of finely powdered pyrites (bisulphuret of iron) with 40 of common salt for sixty hours, and lixiviating the brownish-red mass which results, and from which about 45 parts of crystals of sulphate of soda are obtained. The addition of carbonaceous matter accelerates the process and increases the product. The manufacturers of bleaching-powder furnish large supplies of sulphate of soda. (See *Chloride of Lime.*)

In whatever way the sulphate of soda is obtained, the following are the processes for its decomposition. (See Aikin's *Dictionary*—Art. *Muriate of Soda.*)

Decomposition of Glauber's Salt by the combined Action of Chalk and Charcoal.

"Take 1000 lbs. of calcined Glauber's salt and 550 lbs. of charcoal, and mix the two ingredients accurately together by grinding; when the mixture appears complete, add by degrees 1000 lbs. of washed chalk, and continue the grinding till this also is mixed with the other materials. Now let a reverberatory furnace be lighted, and as soon as it is red-hot, let it be charged with 400 or 500 lbs. (more or less, according to the size of the furnace) of the above mixture, and close the door. During the first part of the process, while the materials are yet pulverulent, the flame must be kept as gentle as possible, lest it should carry part of the powder up the chimney ; but as soon as the matter begins to clot, the flame may be increased. At this time the mass must be carefully worked about with an iron rake, in order to expose fresh surfaces to the action of the flame. When the whole has acquired a pasty consistence, jets of inflamed sulphuretted hydrogen will be perceived to issue from every part, accompanied by a moderate but very perceptible explosion and effervescence; and during the whole of this stage of the process the rake must be used very vigorously, in order to expedite the disengagement of the gas. When the jets of flame cease, and the matter becomes nearly fluid, the rake may be withdrawn, and a bar of cold iron is to be introduced from time to time, in order to judge of the progress of the operation by the sample that adheres to the end of it: if this cracks as it grows cold, and presents an uniform granular texture, the heat has been continued long enough, and the matter must then be speedily withdrawn, lest it should be fretted by the further action of the fire. The flame being accordingly turned off for a few minutes, the mass returns to a pasty consistence, and is withdrawn from the furnace by means of the rake. As soon as it becomes solid by cooling, it is to be broken into moderate-sized pieces, and kept for some days in a damp cellar, where it imbibes a considerable quantity of water and carbonic acid, falls to powder, and at the same time parts almost entirely with the sulphuretted hydrogen, to which its hepatic smell and flavour, when recent, are owing. It may now be brought to market, without any further preparation ; or the alkaline part may be extracted and sold separately.

" In order to separate the alkaline from the earthy part, lixiviation with cold water must be had recourse to : the clear liquor by evaporation to a pellicle, and subsequent cooling, deposits crystals of carbonated soda ; and the mother-water, consisting chiefly of semicaustic soda, must be boiled down to dryness, and afterwards calcined till it is as white as pearlash, in which state it is well fitted for the glass-makers.

"500 lbs. of raw materials treated as above described, afford 276 lbs. of rough soda, of which 100 lbs. yield by lixiviation 37 lbs. 8 oz. of crystallized carbonate and 23 lbs. 2 oz. of dry semicaustic soda, with a small admixture of sulphuret of lime, and of other salts accidentally contained in the original sulphate."

Decomposition of Glauber's Salt by means of Iron and Charcoal.

"Take	200 lbs.	calcined Glauber salt.
	40	powdered charcoal.
	65	clippings of iron plate or old iron.
	22	charcoal, in the state of small coal.
	327 lbs.	

"Having mixed the sulphate of soda with the powdered charcoal, let it be introduced into the reverberatory furnace, and treated for the first hour exactly as described in the foregoing process; then bring the mixture to complete fusion, and add 40 lbs. of the clippings, stirring the materials well at the same time with an iron rake, in order to mix them more completely. In a short time after, the matter, which was at first quite fluid, will become pasty, accompanied with much foaming, and boiling till the clippings are dissolved. As soon as this takes place, 16 lbs. of small coal must be stirred in, which will immediately excite the disengagement of sulphuretted hydrogen mentioned in the former process. When this appearance begins to slacken, the remaining 25 lbs. of clippings and 6 lbs. of small coal are to be added in succession, and the stirring is to be diligently continued till the jets of inflamed gas almost cease. When this happens, the matter still fluid is to be run into moulds of sand, where it solidifies.

"The rough soda thus prepared weighs 215 lbs., is of a blackish-brown colour, which becomes still darker by the contact of the air: when broken it has a kind of metallic lustre, and a close striated texture. To the taste it is caustic and hepatic. By exposure to a moist atmosphere it becomes covered with a yellow efflorescence, and quickly falls to powder, with a considerable disengagement of heat and sulphuretted hydrogen; at the same time it absorbs carbonic acid and water, so as to increase in weight, by an exposure of about twenty days, in the proportion of 5 to 8.

"From the 215 lbs. of rough soda thus obtained, and increased by absorption of air and moisture to 344 lbs., may be obtained, by lixiviation and crystallization, 152 lbs. of carbonated soda; and the uncrystallizable mother-water will afford by evaporation about 47 lbs. of semicaustic soda, mixed with a little charcoal, sulphuret of iron, and other impurities. The insoluble residue weighs about 185 lbs., and is sulphuret of iron, with a little charcoal, in a state highly favourable for vitriolization."

Bisulphate of Soda is obtained by adding sulphuric acid to a hot solution of sulphate of soda. It crystallizes in rhombic prisms, soluble in twice their weight of water at 60°, and containing water of crystallization. (Crell's *Annals*, 1796.)

An anhydrous bisulphate of soda, composed of

1 proportional of soda	. . .	=	32
2 proportionals of sulphuric acid	(40 × 2)	=	80
			112

may be obtained by gently heating together in a platinum crucible 10 parts of dry sulphate of soda and 7 of sulphuric acid (specific gravity 1.85); the water of the acid escapes, and the residue may then be fused: it furnishes a very soluble but not a deliquescent salt, which, when distilled at a high temperature, affords anhydrous sulphuric acid.

Ammonio-sulphate of Soda is a triple salt, formed by saturating the bisulphate with ammonia. (Crell's *Annals*, 1796, i.)

Phosphuret of Sodium possesses the general properties cf the corresponding compound of potassium.

Hypophosphite of Soda is very soluble both in alcohol and water.—*Annales de Chim. et Phys.* ii. 142. It may be obtained by mixing hypophosphite of lime with a slight excess of carbonate of soda, filtering, evaporating to dryness, and digesting in alcohol, which dissolves the hypophosphite, and which by very careful evaporation may be obtained in prismatic crystals.

Phosphite of Soda has not been examined.

Phosphate of Soda crystallizes in rhomboidal prisms, very fusible, soluble in four parts of water at 60° and two parts at 212°, and efflorescing when exposed. It has a pure saline taste. It consists, exclusive of water of crystallization, of

1 proportional of soda	. . .	= 32
1 ,, phosphoric acid	. .	= 28
		60

The crystals contain about 12 proportionals of water. This salt is usually obtained for pharmaceutical purposes by saturating the impure phosphoric acid, obtained from calcined bones by sulphuric acid (see *Phosphorus*), with carbonate of soda: the liquor is filtered, evaporated, and set aside to crystallize. It was introduced into pharmacy by Dr. Pearson; it is the *sal perlatum* of some old writers.

When heated, phosphate of soda fuses and boils up, and having lost its water of crystallization, it runs into a clear glass, which becomes opaque on cooling; and if redissolved in water, the crystals present some peculiarities which have been noticed by Mr. Clarke, of Glasgow (*Edinburgh Journal of Science*, No. xiv.) He has also described a phosphate of soda containing 7½ equivalents of water. If a globule be heated before the blow-pipe, it assumes the dodecaëdral figure as it cools.

Biphosphate of Soda.—Treated with sulphuric acid, phosphate of soda is only partly decomposed, a *biphosphate of soda* being formed, which is more soluble than, and not so easily crystallizable as, the phosphate; or a biphosphate may be obtained by adding excess of phosphoric acid to the phosphate. According to Mitscherlich, it yields two different forms of crystals, which are rhombic prisms.

Ammonio-phosphate of Soda exists in human urine, whence it was procured by the early chemists under the names of *microcosmic* and *fusible salt*. When exposed to heat the ammonia is expelled, and a *biphosphate of soda* remains: it appears to consist of 2 proportionals of phosphoric acid = 56; 1 of soda = 32, and 1 of ammonia = 17 (Fourcroy, *Ann. de Chim.* vii. 183): or, according to Mitscherlich, of 1 proportional of phosphate of soda, 1 of phosphate of ammonia, and 10 of water.

Potasso-phosphate of Soda is obtained by saturating the excess of acid in the biphosphate of potassa with soda. It consists, according to Mitscherlich, of one proportional of phosphate of potassa, one of phosphate of soda, and seventeen of water.

Carbonate of Soda is chiefly obtained by the combustion of marine plants, the ashes of which afford, by lixiviation, the impure alkali called *soda*. Two kinds of rough soda occur in the market, *barilla* and *kelp*; besides which, some *native carbonate of soda* is also imported. Barilla is the semifused ash of the *salsola soda*, which is largely cultivated upon the Mediterranean shore of Spain, in the vicinity of Alicant. Kelp consists of the ashes of sea-weeds, which are collected upon many of the rocky coasts of Britain, and burned in kilns, or merely in excavations made in the ground and surrounded by stones. It seldom contains more than five per cent. of carbonated alkali, and about 24 tons of sea-weed are required to produce one ton of kelp. The best produce is from the hardest *fuci*, such as the *serratus*, *digitatus*, *nodosus*, and *vesiculosus*. (Mac Culloch's *Western Islands*, vol. i. p. 122.) The rough alkali is contaminated by common salt, and other impurities, from which it may be separated by solution in a small portion of water, filtrating the solution, and evaporating it at a low heat: the common salt may be skimmed off as its crystals form upon the surface. Other modes of obtaining carbonate of soda by the decomposition of common salt, and of sulphate of soda, have been, or will be, noticed; and it not unfrequently occurs in an efflorescent form upon walls containing lime and common salt. It is found in some mineral waters. A very pure carbonate of soda may be obtained by calcining acetate of soda at a red heat, and lixiviating the residue.

The primitive crystalline form of carbonate of soda is an oblique rhombic prism, the modifications of which have been described by Mr. Brooke (*Ann. of Phil.*, *N. S.* vi. 287). It is soluble in twice its weight of water at 60°, and in less than its own weight at 212°. "The strongest solution that can be preserved at the temperature of the atmosphere has the specific gravity 1.26; but even this is liable to partial crystallization." (HENRY.) Its taste is strongly alkaline, and it greens vegetable blues. It consists, in its anhydrous state, of

1 proportional of soda = 32
1 „ carbonic acid = 22

Equivalent of dry carbonate of soda = 54

Its crystals contain ten proportionals of water, and are, therefore, composed of

Anhydrous carbonate		54
Water	(9 × 10)	90
Equivalent of crystallized carbonate of soda		144

This water may be expelled by heat. They fuse in their water of crystallization at about 150°, but effloresce by exposure to air. This salt is the *Sodæ Subcarbonas* of the *Pharmacopœia.*

In the analysis of barilla, kelp, and other impure kinds of soda, to ascertain the relative proportion of soda, it may be useful to know that 100 parts of dilute nitric acid, specific gravity 1.36, will saturate 50 parts of dry carbonate of soda, which are equivalent to about 29 of pure soda; or 460 grains of dilute sulphuric acid, specific gravity 1.141, neutralize 100 grains of the dry carbonate. From either of these data, the quantity of real alkali in any sample of the rough salt may easily be calculated. (See *Carbonate of Potassa.*) As 91 grains of sulphuric acid, specific gravity 1.85 are the equivalent of 100 grains of dry carbonate of soda, that weight of acid must be used in the centesimal alkalimeter.

It has already been stated that, when excess of chlorine is passed into a solution of carbonate of potassa or of soda, that carbonic acid is expelled, and chlorides and chlorates formed: by peculiar management, however, chlorine may be combined with a solution of carbonate of soda, and the resulting combination has, from the uses made of it, been termed *Labarraque's disinfecting soda liquid.* It is obtained as follows: 2800 grains of crystallized carbonate of soda are dissolved in 1.28 pints of water, and being put into a Woulfe's apparatus, the chlorine slowly evolved from a mixture of 967 grains of salt with 750 grains of black oxide of manganese, and 967 grains of sulphuric acid previously diluted with 750 grains of water, is carefully passed into it. No carbonic acid is evolved, and a pale yellow liquid is the result; its taste is sharp, saline, and astringent, and at first reddens, and then bleaches turmeric paper. It is but little changed by a boiling heat, and gives out no chlorine. By *careful* evaporation, it furnishes crystals which produce the original liquid when redissolved ; but exposed to the air, and suffered to evaporate spontaneously, the chlorine escapes, and crystals of carbonate of soda are obtained. (Faraday, *Quarterly Journal*, *N. S.*, vol. ii. p. 84.)

Bicarbonate of Soda is formed by passing carbonic acid through a strong solution of the subcarbonate. Small crystals are deposited, which, when very carefully dried at common temperatures, consist of 1 proportional of dry bicarbonate + 2 proportionals of water. The following, therefore, is the composition of the dry and crystallized bicarbonate of soda :—

1 proportional of soda . . .	32	
2 ,, carbonic acid . .	44	
	76	dry salt
2 ,, water . . .	18	
	94	cryst. ditto.

The bicarbonate of soda has a very slightly alkaline taste, and it is much less soluble in water than the subcarbonate. It loses carbonic acid if moistened and left in the vacuum of an air-pump, and the gas is also evolved when one part of the salt is boiled with four of water. In these cases the salt appears to be converted into a *sesqui-carbonate.* (*Quarterly Journal*, xv. 383.) At a red heat, bicarbonate of soda loses its water, and half its acid, and becomes converted into dry carbonate of soda.

This salt, as well as the bicarbonate of potassa, may be obtained by treating their respective carbonates with carbonate of ammonia ; pure ammonia is evolved and bicarbonates are formed.

In the manufacture of this bicarbonate for the purpose of commerce, 160lbs. of carbonate may be dissolved in 13 gallons of water, and carbonic acid thrown into the solution in a proper apparatus. The bicarbonate falls as it forms to the amount of about 50lb., and being separated from the solution may be conveniently dried by pressure in an hydraulic press, and subsequent exposure to heat not exceeding 100°. A fresh portion of carbonate is dissolved in the mother liquor, and the operation repeated as before.

A mixture of the carbonates of soda occurs native in great abundance in Africa, in the province of Gahena, near Fezzan. The natives call it *Trona*. It has been analyzed by Mr. R. Phillips, who considers it as a compound intermediate between the carbonate and bicarbonate, composed of 3 proportionals of acid and 2 of base, or 1 soda + $1\frac{1}{2}$ acid; hence he terms it a *sesqui-carbonate of soda.—Quarterly Journal*, vii. p. 298.

A very productive soda-lake also exists in South America in Maracaybo, one of the provinces of Venezuela.—*Quarterly Journal*, i. p. 188.

Sodium and Cyanogen act with the same phenomena as potassium, and the hydrocyanate of soda is obtained in the same way. *Sulpho-cyanate of soda* is formed as the corresponding salt of potassa; it forms deliquescent rhombic crystals.

Borate of Soda—Borax.—This salt, which has been very long known, is imported from India in an impure state, under the name of *Tincal*, *Pounxa*, or *Chrysocolla*, which, when purified, is called *Borax*. It has also lately been manufactured by combining soda with native boracic acid, imported from the South of Italy. It crystallizes in irregular hexaëdral prisms, slightly efflorescent. Its taste is alkaline and styptic. It is soluble in 20 parts of water at 60°, and in six parts of boiling water; or, according to Berzelius, in 12 of cold and 2 of hot water, proportions which I believe more correct. When heated it loses water of crystallization, and becomes a porous friable mass, called *calcined borax*. At a red heat it runs into a transparent glass, which, by exposure to air, becomes opaque and pulverulent upon the surface. It consists, according to Bergman, of

34	acid
17	soda
49	water
100	

proportions which nearly accord with those assigned by Gmelin. According to Dr. Thomson, the crystallized salt consists of

1 proportional of soda	= 32
2 proportionals of boracic acid	= 48
8 „ water	= 72
	152

Sulphuric acid decomposes this salt, producing sulphate of soda and boracic acid (see page 356). It is also decomposed by nitric and muriatic acids, and by the greater number of the vegetable acids. It has a place in the *Pharmacopœia*, and is sometimes used as a flux.

Muslin and other articles of clothing may be rendered, to a certain extent, incombustible, by steeping them in a solution of borax: when dry, they cannot readily be inflamed.

Fluoborate of Soda forms prismatic crystals of a bitter and sour taste, easily soluble in water, fusible, and anhydrous. (Berzelius.)

The salts of sodium are soluble in water. They are not precipitated either by pure or carbonated alkalis, or hydrosulphuret of ammonia, or ferro-cyanate of potassa; they produce no precipitate in solution of muriate of platinum, and do not convert sulphate of alumina into octoëdral alum.

Potassium and sodium form an alloy, which, if composed of one part of potassium and three of sodium, remains fluid at 32°. Equal parts of the metals form a brittle crystallizable alloy.

Section III. Lithium.

In the analysis of a mineral, called *petalite*, M. Arfwedson discovered between 5 and 6 *per cent.* of an alkaline substance, which was at first supposed to be soda; but, finding that it required for its neutralization a much larger quantity of acid than soda, he was led to doubt its identity with that alkali, and the further prosecution of his inquiries fully demonstrated that it possessed peculiar properties. The mineral called *triphane*, or *spodumene*, also affords the same substance, to the amount of nearly 9 *per cent.*: the term *lithia*, deduced from its lapideous original, has been applied to it. It has also been detected in a few other minerals, and in certain mineral waters in Bohemia.

The following is the mode of obtaining lithia from the above substances:—Reduce the mineral to a fine powder, and fuse it with about half its weight of potassa; dissolve the fused mass in muriatic acid, filter, and evaporate to dryness; digest the dry mass in alcohol; the only substance present, soluble in that liquid, is the *muriate of lithia*, which is taken up, and by a second solution and evaporation is obtained pure. It may be decomposed by digesting carbonate of silver in its aqueous solution, by which a carbonate of lithia is formed, decomposable by lime, in the way of the other alkaline carbonates *.

When lithia is submitted to the action of the Voltaic pile, it is decomposed with the same phenomena as potassa and soda; a brilliant white and highly combustible metallic substance is separated, which may be called *lithium*, the term *lithia* being applied to its oxide.

The properties of this metal have not hitherto been investigated, in consequence of the difficulty of procuring any quantity of its oxide.

Pure lithia is not very soluble in water; its solution tastes acrid like the other fixed alkalis. It acts powerfully on vegetable blues, converting them to green. It is very sparingly soluble in alcohol. It does not deliquesce by exposure, but absorbs carbonic acid and becomes opaque: it affords no precipitate with muriate of platinum, in which it differs from potassa, but resembles soda. It attacks platinum in its pure and carbonated state, and hence must be fused in a silver crucible.

Obtained by evaporating its aqueous solution, lithia is in the state of *hydrate*, the composition of which has not been ascertained: it melts at a red heat, retaining water.

Direct experiments upon the composition of lithia are yet wanting. By calculation from the composition of the sulphate, as analyzed by Vauquelin, it would appear to contain about 55.2 lithium + 44.8 oxygen; and, by other experimentalists, nearly the same results have been admitted, so that the number 10 has been assumed as the equivalent of lithium, and lithia to consist of

1 proportional of lithium . . . . = 10
1 „ oxygen . . . . = 8

Equivalent of lithia . . . . = 18

Chloride of Lithium—obtained by evaporating the muriate

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* See the article COMBINATIONS OF LITHIUM in the next Chapter.

to dryness, and fusing it, is a white semi-transparent substance. It evidently differs from the chlorides of potassium and sodium, in being extremely deliquescent; in being soluble in alcohol; in being decomposed when strongly heated in the open air, when it loses chlorine, absorbs oxygen, and becomes highly alkaline; in being very difficultly crystallizable in cubes; and in tinging the flame of alcohol of a red colour.

Iodide of Lithium.—The action of iodine, of hydriodic acid, and of iodic acid, on lithia has not been examined, nor have its compounds with bromine been investigated.

Fluoride of Lithium is very difficultly soluble. Its solution deposits small opaque crystals.—*Berzelius.*

Nitrate of Lithia is a very soluble deliquescent salt, fusible and decomposed by heat; its taste is cooling; it crystallizes in rhomboids; and is soluble in alcohol.

Sulphuret of Lithium.—The action of sulphur on lithium and lithia appears analogous to its action on potassium and potassa, but the compounds have not been precisely examined.

Sulphate of Lithia crystallizes in small rectangular prisms, perfectly white, and possessed of much lustre. Their taste is saline, and their solubility intermediate between that of sulphate of potassa and sulphate of soda. The crystals contain no water, and fuse at a heat below redness. Their solution occasions no change in solution of platinum, nor in tartaric acid. They consist of

Sulphuric acid	69.18
Lithia	30.82
	100

According to Berzelius, sulphate of lithia contains water of crystallization, and may be regarded as a compound of

1 proportional of	lithia	= 18
1 ,,	sulphuric acid	= 40
1 ,,	water	= 9
Equivalent of sulphate of lithia		= 67

Bisulphate of Lithia has been described as crystallizing in hexangular tables; but Berzelius denies that it is a distinct salt: he, however, admits that sulphate of lithia forms larger crystals when the solution contains excess of acid.

Phosphate of Lithia has been examined by Dr. Gmelin: it may be obtained by adding phosphoric acid to sulphate of lithia; no precipitate is at first formed, but on adding excess of ammonia, an insoluble phosphate of lithia falls. This property enables us to separate lithia from potassa and soda. The phosphate of lithia may be decomposed by dissolving it in acetic acid and adding acetate of lead: *acetate of lithia* remains in solution.

Biphosphate of Lithia is obtained in small crystals by dissolving the phosphate in phosphoric acid.

Carbonate of Lithia.—When a strong solution of carbonate of potassa is added to sulphate of lithia, a white precipitate of *carbonate of lithia* is formed. It requires about 100 parts of water at 60° for its solution. It is insoluble in alcohol. It is fusible, alkaline, effervesces with acids, and absorbs carbonic acid from the air. A solution of this carbonate, containing only 1-1000th of its weight, acts strongly upon vegetable colours. It is decomposed by lime and baryta. It consists of

1 proportional of lithia . . . . . = 18
1 ,, carbonic acid . . . . = 22
40

Borate of Lithia much resembles borate of soda.

It appears, from the preceding statement, that lithia is distinguished from potassa and soda by its greater saturating power in respect to acids: that is, by its lower equivalent number; and by forming difficultly soluble salts with phosphoric and carbonic acids. Chloride of lithium is highly deliquescent, and dissolves in strong alcohol, which enables us to separate it from the chlorides of potassium and of sodium. This solution burns with a purplish flame, and the same tint is communicated to the flame of the blowpipe when any salt of lithia is fused upon a thin slip of platinum foil; they also corrode that metal, and leave a yellow spot at the point of action. Lithia is distinguished from the alkaline earths by forming soluble salts with sulphuric and oxalic acids, and by the alkaline re-action of its carbonate upon vegetable colours.

Section IV. Calcium.

When lime is electrized negatively in contact with mercury, an amalgam is obtained, which, by distillation, affords a white metal. It has been called *calcium;* and when exposed to air, and gently heated, it burns and produces the *oxide of calcium,* or *lime.*

The combinations of lime are very abundant natural products, and of these the *native carbonate,* which, more or less pure, constitutes the different kinds of marble, chalk, and limestone, and which is also the leading hardening principle of shell, coral, &c., may be considered as the most important.

Lime may be obtained in a state of considerable purity by exposing powdered white marble to a white heat for an hour, which expels the carbonic acid. To obtain absolutely pure lime, white marble may be dissolved in dilute muriatic acid, a little ammonia added to the solution, and filtered: carbonate of ammonia is then added, and the precipitate dried, washed, and exposed for a sufficient time to a white heat. Its colour is light grey; it is acrid and caustic, and converts the vegetable blue tests to green; its specific gravity is 2.3; it is very difficult of fusion, but remarkably promotes the fusion of most other earthy bodies, and is therefore used in several metallurgic processes as a cheap and powerful flux. When quite pure it can only be fused in very minute particles by the oxygen blowpipe, or by the Voltaic flame. When intensely heated it is remarkable for its luminosity. (See page 127.) It is an essential ingredient in mortar and other cements used in building. Exposed to air it becomes white by the absorption of water and a little carbonic acid.

Different experimentalists agree in representing lime by the equivalent 28, and considering it as composed of

1 proportional of calcium	= 20
1 „ oxygen	= 8
	28

When a small quantity of water is poured upon lime, there is a great rise of temperature resulting from the solidification of a portion of the water, and a bulky white powder is obtained, called *slacked lime,* which is a *hydrate,* and which appears to consist of

1 proportional of lime . . . = 28
1 „ water . . . . = 9
Equivalent of hydrate of lime . . . = 37

Lime may be obtained in a crystalline form by placing lime-water under the receiver of an air-pump, containing another vessel of sulphuric acid. The water is thus slowly evaporated, and imperfect six-sided crystals of hydrate of lime are formed. —Gay-Lussac, *Annales de Chimie et Phys.*, i. 334. In composition these crystals resemble the above hydrate. Exposed to the air, they gradually crumble down into carbonate of lime.

At the temperature of 60°, 750 parts of water are required for the solution of one part of lime, forming *lime-water.* Boiling water, however, as Mr. Dalton first observed (*New System of Chem. Phil.*), does not dissolve so large a quantity ; one part of lime requiring, according to Mr. R. Phillips, 1280 parts of water at 212° for its solution (*Ann. of Phil.*, N.S., i. 107) ; and water at 32° has its solvent power much augmented, one part being soluble in 656 of water at that temperature. When lime-water is boiled, a portion of the lime is accordingly precipitated or aggregated, according to Mr. Phillips, into small crystalline grains. The cause of this crystallization he refers “ to the effect which heat sometimes produces, of increasing instead of diminishing the attraction of cohesion, where this attraction is associated with a tendency to crystallize. This crystalline attraction, increased by that of the lime for a definite portion of water, is then greater than the attraction of the hydrate of lime for the water of solution, and the consequence is that crystals are formed.”

Lime-water is limpid and colourless ; its taste is nauseous, acrid, and alkaline, and it converts vegetable blues to green. It is usually prepared by pouring warm water upon powdered lime, and allowing the mixture to cool in a close vessel ; the clear part is then decanted from the remaining undissolved portion of lime. When lime-water is exposed to the air, a pellicle of carbonate of lime forms upon its surface, which, if broken, is succeeded by others, until the whole of the lime is thus separated in the form of an insoluble carbonate. Lime-water is used in medicine as an antacid.

When oxygen is passed over heated lime, it is absorbed, and a portion of *peroxide of calcium* is formed. A hydrated peroxide of calcium is thrown down, according to M. Thenard, when lime-water is dropped into oxygenated water. This compound consists of

1 proportional of calcium . . . = 20
2 „ oxygen (8 × 2) . . = 16
Equivalent of deutoxide of calcium . . = 36

Chloride of Calcium occurs native in sea-water and in some mineral waters; it is produced artificially by heating lime in chlorine, in which case oxygen is evolved, or by evaporating *muriate of lime*, obtained by dissolving carbonate of lime in muriatic acid, to dryness, and exposing the dry mass to a red heat in closed vessels. Chloride of calcium consists of

1 proportional of calcium . . . = 20
1 „ chlorine . . . = 36
Equivalent of chloride of calcium . . = 56

This compound has a strong attraction for water; it deliquesces when exposed to air, and becomes what used to be called *oil of lime*. It is difficultly crystallizable from its aqueous solutions; with care, however, it may be obtained in six-sided prisms, consisting of the chloride combined with water, in the proportion, according to R. Phillips (*Ann. of Phil.*, vi. 343), of

1 atom chloride of calcium . .	56	50.9
5 „ water (9 × 6) . . .	54	49.1
	110	100

It is most readily crystallized by exposing its solution to the temperature of 32°. Its taste is bitter and acrid; one part of water, at 60°, dissolves four parts of the chloride. Its solubility, however, is greatly influenced by temperature, for at 32° one part of water will not dissolve more than two of the salt, and at 212° it takes up nearly any quantity. It is copiously soluble in alcohol, and much heat is evolved during the solution. When fused it acquires a phosphorescent property, as was first observed by Homberg, and hence it was termed *Homberg's phosphorus*. It is abundantly produced in the manufacture of carbonate of ammonia, from the decomposition of muriate of ammonia by lime, and hence has sometimes been called *fixed sal ammoniac*. The production of cold by mixing muriate of lime with snow has already been adverted to. In its fused state chloride of calcium is very useful for drying certain gaseous bodies, but where the quantity of the gas is to be ascertained, its powers of absorption in certain cases must not be overlooked.

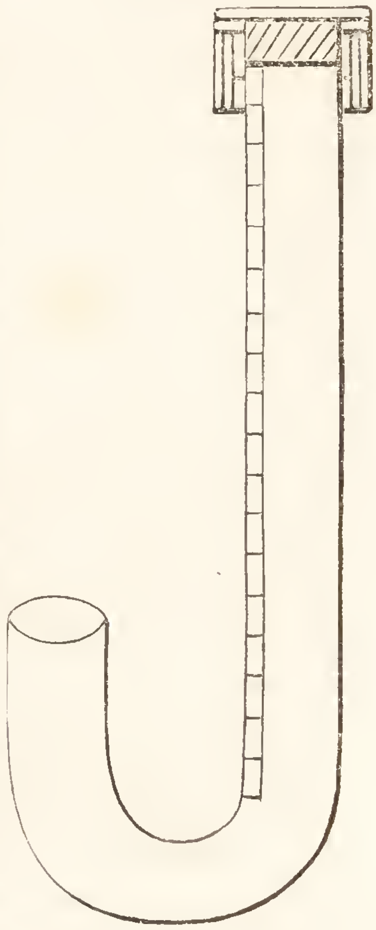
Mr. Faraday has shewn (*Quart. Journal*, v. 74) that chloride of calcium absorbs large quantities of ammoniacal gas, during which it swells, cracks, splits in all directions, and at last crumbles down into a white powder. Exposed to the atmosphere it deliquesces less rapidly than the original chloride. Thrown into water it dissolves, forming a strong alkaline solution. Heated, it gives off ammonia, and the chloride remains unchanged. Immersed into chlorine, the ammonia burns off with a pale yellow flame. Twenty grains of the compound furnished, when heated, about twenty cubic inches of ammonia. Mr. Faraday availed himself of this compound for the purpose of condensing ammonia into a liquid.

Pelletier has stated, that if carbonic acid be passed through a solution of muriate of lime, the whole becomes a hard solid mass. If sulphuric acid be poured into a strong solution of muriate of lime, the whole congeals into a solid mass of sulphate of lime.

A substance called *Oxymuriate of Lime* is abundantly employed as a bleaching material, and manufactured by passing chlorine into leaden chambers containing hydrate of lime in fine powder, by which the gas is copiously absorbed with extrication of heat. This is a compound of chlorine and lime. When heated, it gives off a large quantity of oxygen, and a chloride of calcium results, an experiment which shows the superior attraction of calcium for chlorine compared to oxygen, the latter being expelled from the lime.

Dr. Ure has contrived an instrument for the speedy analysis of this salt for the purposes of the artist, by which the quantity of chlorine in any given sample may be determined. (*Quart. Journ.*, xiii. 21.)

"It consists of a glass tube, of about five cubic inches capacity, shaped as in the adjoining figure, and graduated into cubic inches and tenths. It is to be closed at top with a brass screw cap, and, at its recurved end below, with a good cork. Pour mercury into the upper orifice, till the tube be nearly full, leaving merely space to insert ten grains of the bleaching-powder, made into a pellet-form with a drop of water. Screw in the cap-plug rendered air-tight by leather. Remove now the cork from the lower end, (also full of mercury,) and replace a little of the liquid metal by dilute muriatic acid (specific gravity 1.1). By dexterous inclination of the instrument, the acid is made to flow up through the mercury. Instantly on its coming into contact with the pellet, the chlorine is disengaged, the mercury flows out into a basin ready to receive it, while the resulting film of muriate of lime protects the surface of the metal almost completely from the gas. With an apparatus of this kind, which indeed is the same as that which I have long used for analysing limestones and marbles (see article *Carbonate* in my Chemical Dictionary), I get good accordances with the results derived from the loss of weight suffered by a like quantity of the chloride, when it is dissolved in dilute muriatic acid. Since a cubic inch of chlorine may be estimated in round numbers at $\frac{3}{4}$ of a grain, we may expect 10 grains of bleaching-powder to yield from 3 to 4 cubic inches of that gas, or by weight, from 20 to 30 per cent., a wide range of power, which it is well worth the bleacher's or paper-maker's while to ascertain. If carbonic acid be suspected, we need only agitate the mercury through the gas, adding some of the metal from time to time as the absorption proceeds. The carbonic acid will remain uncondensed at the top, and may be estimated in the usual way."



The composition of bleaching powder has been variously stated. Mr. Dalton (*Ann. of Phil.*, i. 15, and ii. 6) considers it as a hydrated subchloride of lime, containing two proportionals of lime and one of chlorine; and the same opinion is adopted by Thomson (*Ann. of Phil.* xv. 401), and by Welter (*Ann. de Chim. et Phys.*, vii. 383). Dr. Ure, however, shows, in the paper already quoted, that the quantity of chlorine absorbed is variable; he analyzed a specimen of good commercial bleaching powder, and found it composed of 46 lime, 23 chlorine, and 31 water: a specimen prepared by himself with pure hydrate of lime contained 45.40 lime, 40.32 chlorine, and 14.28 water, and he found the condensation of chlorine to vary with the pressure, the degree of exposure, and the quantity of water present. Upon the whole, it is not improbable that bleaching powder consists of a chloride of lime, containing one proportional of chlorine and one of lime, mixed with a varying proportion of hydrate of lime; and that when water acts upon the compound the solution contains a chloride of lime.

Chlorate of Lime is a very soluble deliquescent salt of a sharp bitterish taste. It is most easily produced by dissolving carbonate of lime in chloric acid. Exposed to heat, oxygen is evolved, and a chloride formed.

Iodide of Calcium is obtained by dissolving carbonate of lime in hydriodic acid, evaporating to dryness, and heating the residue in a close vessel till it fuses: it is a deliquescent gray substance, which, heated in the air, absorbs oxygen and evolves iodine. It consists of

1 proportional of calcium . . .	=	20
1 „ iodine	=	125
Equivalent of iodide of calcium . .		145

Dissolved in water and slowly evaporated it furnishes deliquescent crystals, usually called *hydriodate of lime;* they are composed of the iodide and water.

Iodate of Lime is very difficultly soluble; it crystallizes in small quadrangular prisms, requiring 400 parts of water for their solution; in a strong heat oxygen and ultimately iodine are evolved, and if air be present lime remains.

Bromide of Calcium and *Bromate of Lime* have not been examined.

Fluoride of Calcium—Fluor Spar.—These terms have been applied to a combination of calcium and fluorine, consisting probably of

1 proportional of calcium	. . .	— 20
1 „ fluorine	. . . .	— 16
		36

Fluor spar is a mineral found in many parts of the world, but in great beauty and abundance in England, and especially in Derbyshire. Here it is commonly called *Derbyshire spar*, or by the miners of that county *blue John*. It is usually found in cubic crystals, which may easily be cleaved into octoëdra, sometimes considered as its primitive form. Its colours are extremely various. Its specific gravity 3. It phosphoresces when exposed to a heat a little below redness. It generally occurs in veins; in the Odin mine at Castleton in Derbyshire, it is found in detached masses, from an inch to more than a foot in thickness; their structure is divergent, and the colours, which are various, disposed in concentric bands. It is the only variety which admits of being turned in the lathe into vases and other ornamental articles.

Compact fluor is a scarce variety: the finest specimens come from the Hartz. A third variety is *chlorophane*, so called from the beautiful pale green light which it exhibits when heated.

The nature of the colouring matter of blue and green fluor spar is not exactly understood. It is liable to fade, and the blue varieties become red and brown by heat.

Fluoride of calcium exists, according to Berzelius, in bones, urine, and the enamel of teeth, in the human subject; he also found it in minute quantities in some of the Carlsbad waters. It is produced artificially by saturating dilute hydrofluoric acid with newly precipitated and moist carbonate of lime, and may thus easily be collected and dried in the form of white powder. If obtained by precipitating a neutral salt of lime with a soluble fluoride it forms a gelatinous mass, the precipipitation of which is accelerated by the addition of caustic ammonia.

Pure fluoride of calcium is not decomposed by cold sulphuric acid, but forms with it a transparent viscid mixture.

At a temperature of about 100° its decomposition begins, sulphate of lime forms, hydrofluoric acid is evolved, and the mixture grows opaque. If the fluor spar contain silica, then sulphuric acid immediately acts upon it, evolving silico-fluoric acid. Concentrated muriatic and nitric acids dissolve fluoride of calcium without decomposition, and become milky when diluted; but it is doubtful whether such solutions are formed when the fluoride is perfectly pure. It is scarcely soluble in hydrofluoric acid.

Nitrate of Lime is a deliquescent salt, soluble in four parts of water at 60°. It is found in old plaster and mortar, from the washings of which, nitre is procured by the addition of carbonate of potassa. It is composed, according to Phillips (*Quart. Journn.*, v. 167) of

34.4	lime	28
65.6	nitric acid	54
100		82

The production of this salt in artificial nitre-beds has already been adverted to. It may be crystallized, by very slow evaporation, in six-sided prisms: but when obtained from a solution evaporated very low, and set aside in the cold, it appears in the form of groups of acicular crystals, soluble in about two parts of water at 60°, and in less than one part at 212°. It is soluble in alcohol. When exposed to a moderate heat, it undergoes watery fusion; the water then evaporates and the salt fuses; on cooling it concretes into a semi-transparent phosphorescent substance, called from the discoverer of this property *Balduin's phosphorus.* (Birch's *History of the R. S.*, iii. 328.) At a red heat it is decomposed; its acid is dissipated, and pure lime remains. It contains, in its crystallized state, about 25 per cent. of water, and may hence be considered as composed of

1 proportional dry nitrate	82
3 „ water (9 × 3)	27
	109

Nitrate of lime has been found in some mineral waters.

Sulphuret of Calcium is formed by passing sulphuretted hydrogen, or the vapour of sulphuret of carbon, over red-hot lime. A reddish substance is obtained, slowly acted upon by water, and of an hepatic and alkaline taste. When its solution is carefully evaporated in vacuo, white crystals of hydrosulphuret of lime are obtained.

Hydrosulphuret of Lime is also obtained by passing sulphuretted hydrogen through a mixture of quicklime and water.

When lime and sulphur are boiled together in water a yellow liquid is obtained, which contains a compound of lime and bisulphuretted hydrogen. This liquor is sometimes used in the process of bleaching, as a substitute for alkaline leys.

According to Mr. Herschel, crystallized *hydrobisulphuret of lime* is formed when three parts of slacked lime and one of sulphur are boiled in twenty parts of water, and the solution allowed to cool upon the sediment: he dried the crystals by exposure to the absorbent power of a large surface of sulphuric acid, placed under an exhausted receiver. Their form is that of quadrilateral prisms, with dihedral summits. They are sparingly soluble in cold water, the solution having a yellow colour, and an acrid, bitter, and sulphurous taste. They consist of two proportionals of lime, two of sulphur, one of hydrogen, and four of water.—*Edinburgh Philosophical Journal*, i. p. 11, &c.

When sulphurous acid is ground in a mortar with the above crystals its smell disappears, and when filtered it is found to be a solution of *hyposulphite of lime.* By passing sulphurous acid through an aqueous solution of sulphuret of lime, the same product is obtained; and if the solution be filtered and evaporated, at a temperature not exceeding 140°, it furnishes crystals: the temperature of ebullition decomposes it. The crystals are little altered by air, very soluble in water, and insoluble in alcohol. They consist, according to Mr. Herschel, of

			Propor.		
Lime	21.71	=	1	=	28
Acid	36.71	=	2	=	48
Water	41.58	=	6	=	54
	100				130

This salt, therefore, independent of water of crystallization, is a bin-hyposulphite of lime, and its equivalent is 76.

Sulphite of Lime is formed by passing sulphurous acid into a mixture of lime and warm water. It is a white powder, soluble by excess of sulphurous acid, and then separating in prismatic crystals, of difficult solubility, efflorescent, and passing into sulphate of lime by exposure to air.

Hyposulphate of Lime forms transparent soluble crystals, which contain between 26 and 27 per cent. of water of crystallization.

Sulphate of Lime occurs native in selenite, gypsum, and plaster-stone. It is easily formed artificially, and then affords silky crystals soluble in 350 parts of water. When these, or the native crystallized sulphate are exposed to a dull red heat, they lose water, and fall into a white powder (*plaster of Paris*), which, made into a paste with water, soon solidifies. Hence its use in taking casts for busts, figures, and ornaments. Exposed to a very high temperature, short of its fusing point, it loses this property of recombining with water. Dry sulphate of lime requires about 500 parts of water at 60°, and 450 parts at 212°, for its solution. It consists of

1 proportional of lime . .	=	28	=	41.2
1 " acid . .	=	40	=	58.8
		68		100

The crystallized sulphate of lime consists of

1 proportional of anhydrous sulphate .	=	68
2 proportionals of water (9 × 2) . .	=	18
		86

As sulphate of lime is more soluble in water than pure lime, sulphuric acid affords no precipitate when added to lime-water. Nearly all spring and river water contains this salt, and in those waters which are called *hard* it is abundant. It gives to them a slightly nauseous taste. At a very high temperature sulphate of lime is fusible, but it suffers no decomposition; heated with charcoal it is converted into a sulphuret. It dissolves without decomposition in dilute nitric and muriatic acids, and separates from these solutions when concentrated in long silky or transparent crystals. It is decomposed by the alkaline carbonates.

Native Sulphate of Lime occurs in various forms. The crystallized variety is usually called *selenite;* the fibrous and earthy, *gypsum;* and the granular or massive, *alabaster.* The primitive form of selenite is a rhomboidal prism of 113° 8′ and 66° 52′. The crystals are commonly transparent, and of various colours; it is softer than native carbonate of lime, and yields very easily to the nail. It is seldom found in veins, but generally disseminated in argillaceous strata. It occurs in Cumberland at Alston, and in Oxfordshire at Shotover Hill, where it is often accompanied by shells and pyrites, and appears to have resulted from their mutual decomposition. A beautiful fibrous variety is found in Derbyshire, applicable to ornamental purposes.

Massive and granular gypsum is found in this country accompanying the salt-deposits in Cheshire. It abounds at Montmartre, near Paris, and contains organic remains; sometimes it forms entire hills. In the Tyrolese, Swiss, and Italian Alps, it is found upon the primitive rocks, often of the purest white, especially at Montier, near Montblanc, and near the summit of Mount Cenis. It is turned by the lathe, and sculptured into a variety of beautiful forms, more especially by the Florentine artists.

There is a variety of sulphate of lime, which has been called *anhydrous gypsum,* or *anhydrite,* in reference to its containing no water. It is harder than selenite, and sometimes contains common salt, and is then called *muriacite.* It is rarely crystallized, generally massive and lamellar, and susceptible of division into rectangular prisms. It has been found in Derbyshire and Nottinghamshire of a pale blue tint; sometimes it is pink or reddish, and often white. It has been found at Vulpino in Italy, and hence called *Vulpinite.* The statuaries of Bergamo and Milan employ it, and artists know it by the name of *Marbre di Bergamo.* A compound of sulphate of lime and sulphate of soda is found in the salt-mines of New Castile, which mineralogists have described under the name of *Glauberite.*

Phosphuret of Calcium.—By passing phosphorus over red-hot lime, a brown compound is produced, which rapidly decomposes water with the evolution of phosphuretted hydrogen gas. *Hydrophosphuret* and *hypo-phosphite of lime* are also formed, and dissolve, and a phosphate of lime precipitates.

When dilute muriatic acid is poured upon this phosphuret, abundance of phosphuretted hydrogen is liberated.

The best process for obtaining this phosphuret is the following: select a green glass, or porcelain tube, closed at one end, and about eighteen inches long, and one inch diameter, and carefully cover it with a clay lute containing a very little borax. Put an ounce of phosphorus broken into small pieces into the lower end, and fill it up with pieces of clean quicklime, about the size of large peas: place it in an inclined position in a furnace, so that the end containing the phosphorus may protrude, while the upper part of the tube is heating to redness; then slowly draw the cool part into the fire, by which the phosphorus will be volatilized, and passing into the red-hot lime, convert a portion of it into phosphuret. Care should be taken that no considerable portion of phosphorus escapes and burns away at the open end of the tube, which, after the process, should be corked and suffered to cool. Its contents may then be shaken upon a sheet of paper, and the brown pieces picked out and carefully preserved in a well-stopped phial; the white pieces, or those which are only pale brown, must be rejected.

Hypophosphite of Lime may be obtained by boiling phosphorus in thin cream of lime, filtering off the solution, and passing carbonic acid through it, to separate excess of lime. The clear solution evaporated in vacuo furnishes crystals of the hypophosphite. This salt is useful for the preparation of other hypophosphites. It is insoluble in alcohol.

Phosphite of Lime is a difficultly soluble salt, crystallizable by spontaneous evaporation. When its solution is heated, nacreous crystals of a *subphosphite* are deposited, and a very soluble and difficultly crystallizable *biphosphite* remains dissolved.

Phosphate of Lime exists abundantly in the bones of animals; it is also found in the mineral world. It may be formed artificially, by mixing solutions of phosphate of soda and chloride of calcium. It is insipid and insoluble in water, but dissolves in dilute nitric and muriatic acid, and in acetic acid, without decomposition, and is precipitated from these solutions unaltered by caustic ammonia. It is decomposed by sulphuric acid, and thus the phosphoric acid for the production of phosphorus is usually procured. (See *Phosphorus*, Chap. IV. Sect. 4.) It consists of

1 proportional of lime	=	28
1 „ phosphoric acid	=	28
		56

At a very high temperature phosphate of lime fuses into an opaque white enamel.

According to Berzelius, the composition of the precipitate obtained from a mixture of the solutions of phosphate of soda and chloride of calcium varies with the mode of mixing them: if the solution of the phosphate be dropped into the chloride the precipitate is a crystalline powder, and is the neutral salt combined with two proportionals of water. If, on the other hand, the solution of the chloride be gradually added to that of the phosphate of soda, leaving the latter in excess, a *subphosphate of lime* falls, corresponding in composition with bone earth. Berzelius admits the existence of a neutral phosphate, two subphosphates, a biphosphate, and a sesquiphosphate of lime.

Biphosphate of Lime is formed by digesting the phosphate in phosphoric acid. On evaporation crystalline scales are deposited, composed of 1 proportional of lime + 2 of phosphoric acid, or 28 + 56 = 84. The same salt is said to be obtained by digesting the neutral phosphate in muriatic or nitric acids, and evaporating the solution till it furnishes crystals. Distilled with charcoal, one proportional of its acid is decomposed and yields phosphorus, and a neutral phosphate remains.

The phosphoric glass described under the head *Phosphoric Acid* (Chap. IV. Sect. 4.), is considered by Dr. Thomson as a definite compound, which he has termed *quadriphosphate of lime.—System*, vol. ii. p. 460.

" If 100 parts of phosphate lime be digested for twenty-four hours with 87 parts of sulphuric acid diluted with a sufficient quantity of water, and be then filtered, the liquor which passes through contains the whole of the phosphoric acid, with only one-fourth of the lime which existed in the original salt; the remaining three-fourths having formed an insoluble compound with the sulphuric acid. The dissolved salt, therefore, is a compound of 1 atom of lime = 28 + 4 atoms of acid =

112. When evaporated, it forms, on cooling, pearly scales, which have an acid taste, and dissolve readily in water, giving an acid solution of the specific gravity 1.44. When dried and fused in a crucible, a transparent glass is obtained, commonly called *glacial phosphoric acid,* and employed chiefly in the production of phosphorus." (Henry, vol. i. p. 567.)

Native Phosphate of Lime has by some been regarded as a *subphosphate,* in which case it would be composed of 2 proportionals of lime + 1 of phosphoric acid. This compound occurs crystallized and massive, and is known under the names of *apatite, asparagus-stone,* and *phosphorite.* The crystallized variety is found in Cornwall and Devonshire, of singular beauty. Its primitive form is a six-sided prism: it also occurs in volcanic products; and, what is curious, the former is phosphorescent and the latter not. The massive variety is found in Bohemia and in Spain. Till the equivalent of phosphoric acid has been more accurately determined, considerable discrepancies will be found in the accounts given of the composition of the phosphates of lime.

Selenious Acid and Lime.—Berzelius has described a neutral selenite and a biselenite of lime.

Carbonate of Lime is the most abundant compound of this earth. When lime-water is exposed to air, it becomes covered with an insoluble film of carbonate of lime, and hence is an excellent test of the presence of carbonic acid. But excess of carbonic acid re-dissolves the precipitate, producing a supercarbonate. Carbonate of lime is precipitated by the carbonated alkalis from solutions of muriate, nitrate, and sulphate of lime. Exposed for a sufficient time to a red heat, the whole of the carbonic acid escapes, to the amount of 44 per cent., and quicklime is obtained. Hence carbonate of lime consists of

1 proportional of lime . .	= 28	. 56
1 „ carbonic acid .	= 22	. 44
	50	100

Carbonate of lime occurs in nature in great abundance and in various forms. The primitive form of crystallized carbonate of lime, or *calcareous spar,* is an obtuse rhomboid of 105° 5′ and 74° 55′. Its specific gravity is 2.7. It occurs in every kind of rock, and its secondary forms are more numerous than those of any other substance: sometimes it forms fine *stalactites*, of which some of the caverns of Derbyshire furnish magnificent specimens; it is here deposited from its solution in water acidulated by the carbonic acid, and substances immersed in this water become incrusted by carbonate of lime, when the excess of acid flies off, as seen in the *petrifying well of Matlock*. A fibrous variety of carbonate of lime, called *satin spar*, is found in Cumberland.

Another variety, originally found in Arragon in Spain, has been termed *Arragonite;* it occurs in six-sided crystals, of a reddish colour, and harder than the common carbonate. There is an acicular or fibrous variety, found in France and Germany; and the white radiated substance, improperly called *flos ferri*, is also regarded as of the same species. Some varieties contain about 3 per cent. of strontia.

All the varieties of marble and limestone consist essentially of carbonate of lime; of these, *white granular limestone*, or *primitive marble*, is most esteemed; there are, also, many coloured varieties of extreme beauty. It is distinguished from *secondary limestone* by the absence of all organic remains, by its granularly foliated structure, and by its association with other primitive substances.

The most celebrated statuary marble is that of Paros and of Mons Pentelicus near Athens; of these, some of the finest specimens of ancient sculpture are composed. The marble of Carrara, or Luni, on the eastern coast of the Gulf of Genoa, is also much esteemed; it is milk-white and less crystalline than the Parian.

Many beautiful marbles for ornamental purposes are quarried in Derbyshire, and especially the black marble, called also *Lucullite*. Westmoreland and Devonshire also afford beautiful varieties; and in Anglesea, a marble intermixed with green serpentine is found, little inferior in beauty to the *verd antique*.

Among the inferior limestones, we enumerate many varieties, such as *common marble; bituminous limestone*, abundant upon the Avon, near Bristol, and known under the name of *swine-stone* or *stink-stone*, from the peculiar smell which it affords when rubbed; *Oolite* or *Roestone*, of which the houses of Bath are built; and its variety, called *Portland-stone*. *Piso-*

lite consists of small rounded masses, composed of concentric layers, with a grain of sand always in the centre; and lastly, *chalk* and *marl.*

All these substances are more or less useful for ornamental purposes, or for building; they afford quicklime when burned, and in that state are of great importance as manures, and as ingredients in the cements used for building. There is a great variety of limestones used for burning into quicklime, and, generally speaking, any of the varieties may be employed which neither fuse nor crumble into powder at the temperature required to expel the carbonic acid, which is a full red heat.

The following observations on lime-burning are extracted from Aikin's *Dictionary*, art. *Lime* :—

Although all the species of limestone may, by burning, be brought to the state of quicklime, yet we shall find in fact that the substances belonging to the family of *compact* limestone are the only ones that are, or that can be advantageously employed for this purpose in the large way. Sometimes, calcareous spar, and more frequently statuary marble, are used in the laboratory for the purpose of procuring a lime purer than ordinary for the purposes of chemistry. But, owing to the crystalline texture of these substances, the laminæ of which they are composed part from each other during the volatilization of their carbonic acid, so that by the time when they are rendered thoroughly caustic, their cohesion is destroyed, and they are reduced merely to the consistence of sand, a circumstance which must always prevent them from being used in kilns of the common construction. The lime-kiln at present almost universally employed in this country, is a cup-shaped concavity, in a solid mass of masonry, open at the top, and terminated at the bottom by a grate, immediately above which is an iron door that may be opened and closed at pleasure. This simple furnace is first charged with fuel, (either wood or coal, but more commonly the latter,) upon which is afterwards laid a stratum about a foot thick of limestone, broken into pieces not larger than the fist; to this succeeds a charge of fuel; and so on alternately, keeping the kiln always full. The pieces of limestone descend towards the bottom of the kiln in proportion as the fuel is consumed, being in the mean time kept at a pretty full red heat. At this temperature, the water and carbonic acid are driven off; and by the time that the limestone arrives at the bottom of the kiln, which happens in about forty-eight hours, it is rendered perfectly caustic. The door above the grate is then opened, and all the lime below the next descending stratum of fuel is raked out; the remaining contents of the furnace sink down, and a fresh charge is laid on the top. The compact limestone, after having undergone this process, though much lighter and porous than before, still retains its figure unaltered: hence it is readily separable from the ashes of the fuel, and is sufficiently hard to be carried from place to place without falling to pieces.

Cyanuret of Calcium has not been obtained. When hydrate of lime is digested in hydrocyanic acid, a solution of hydrocyanate of lime is formed, which upon evaporation is resolved into ammonia and carbonate of lime.

Sulphocyanate of Lime forms deliquescent acicular crystals, soluble in water and in alcohol.

Borate of Lime is a white tasteless powder of very difficult solubility in water. At a red heat it forms a vitreous mass.

The salts of lime have the following properties:—

Those which are soluble are not altered by pure ammonia, but they are decomposed by potassa and soda. They are also decomposed by the carbonates of potassa, soda, and ammonia, which produce precipitates of carbonate of lime.

Oxalate of ammonia produces in their solutions a white insoluble precipitate of oxalate of lime, which, exposed to a red heat, affords pure lime. Such of the salts as are soluble in alcohol, tinge the edge of its flame of a reddish colour.

The insoluble salts of lime are decomposed by being boiled with carbonate of potassa, and afford carbonate of lime.

Section V. BARIUM.

To obtain this metal, the earth baryta is negatively electrized in contact with mercury: an amalgam is gradually formed, from which the mercury may be expelled by heat, and the metal barium remains; appearing, according to Sir H. Davy, of a dark grey colour, and being more than twice as heavy as water. It greedily absorbs oxygen, and burns with a deep red light when gently heated, producing the oxide of barium.

Oxide of Barium, *Baryta*, or *Barya*, is obtained by exposing the crystals of nitrate of baryta for some time to a bright red heat, or by subjecting artificial carbonate of baryta to an intense heat thoroughly mixed with about 10 per cent. of finely-powdered charcoal. It is of a grey colour, and, when pure, very difficult of fusion. Its specific gravity is about 4, hence the name *Baryta*, as being the heaviest of the substances usually called earths. It eagerly absorbs water, heat is evolved, and a white solid, more fusible than the pure earth, is formed, containing about 10 per cent. of water, which it retains at a red heat. It is very important to establish correctly the equivalent number of baryta, in consequence of the use which is made of it in analyses: Sir H. Davy states it to consist of 89.7 barium, and 10.3 oxygen per cent.; these numbers closely agree with 89.744 and 10.256; and it may be regarded as a compound of

1 proportional of barium	= 70
1 ,, oxygen	= 8
Equivalent of baryta	= 78

and the protohydrate, permanent at a dull red heat, will consist of

1 proportional of baryta	= 78
1 ,, water . . .	= 9
	87

Hydrate of Baryta dissolves in 20 parts of cold and in 2 of boiling water, and, as the solution cools, deposits flattened hexagonal prisms, which contain a large quantity of water, and are easily fusible. According to Mr. Dalton, crystallized baryta consists of 1 proportional o fbaryta and 20 of water; if it be exposed to air it effloresces into a white powder, containing 1 proportional of baryta and 5 of water; it appears, therefore, that there are three hydrates of baryta (*New Chem. Phil.* ii. 522). The aqueous solution, or *baryta water*, is limpid, colourless, and acts energetically on vegetable blues and yellows, changing them to green and brown; it rapidly absorbs carbonic acid, and deposits an insoluble carbonate of baryta. Baryta is also sparingly soluble in alcohol, 1 part requiring about 200 of alcohol for its solution. As baryta, like the alkalis, converts vegetable blues to green, and serves as an intermede between oil and water, it has been called an *alkaline earth*. It has a very acrid caustic taste, and is highly poisonous. It exists chiefly in two natural combinations only, namely, the sulphate and carbonate.

When baryta is heated in oxygen, or when oxygen is passed over baryta heated to redness in a glass tube, the gas is absorbed and a grey compound is obtained, which is the *peroxide of barium;* consisting of

1 proportional of barium . . . . . = 70
2 „ oxygen . . . . = 16
86

By dissolving peroxide of barium in muriatic acid, and precipitating by sulphuric acid, M. Thenard succeeded in obtaining a new and singular compound of oxygen and water, to which the term *peroxide of hydrogen* may be applied. The solution of the peroxide of barium, and the subsequent separation of the protoxide, is repeated a sufficient number of times, in the same portion of dilute muriatic acid; sulphate of silver is then added to separate the muriatic acid, and the sulphuric, which then becomes its substitute, is ultimately removed by baryta. M. Thenard, in his elaborate essay upon this new compound, has shown that the process, although in theory sufficiently simple, presents many practical difficulties, chiefly arising from the impurities contained in the peroxide of barium. To obtain this substance pure, upon which the success of the subsequent operations depends, he gives the following directions. Prepare a very pure nitrate of baryta, and decompose it by a strong heat in a porcelain vessel, by which baryta, containing a portion of silica and alumina, but free from manganese, will be obtained; the latter impurity must always be most cautiously avoided, for oxide of manganese possesses the property of energetically decomposing the oxygenated water.

The baryta, broken into small pieces, is then introduced into a luted glass tube (the glass should not contain lead) large enough to contain about two pounds of it, and being heated to dull redness, a current of dry and perfectly pure oxygen gas is passed through it, which it rapidly absorbs; this operation is to be continued till the oxygen escapes from a small tube inserted into the opposite extremity of the larger one.

The peroxide thus obtained is pale grey, and frequently some pieces are speckled with green, which announces the presence of manganese, and which should be rejected: its distinctive character is, that it crumbles when a few drops of water are added to it, without producing heat.

The process then proceeds as follows. Take a certain quantity of water (about eight ounces for instance), and add to it a sufficiency of pure and fuming muriatic acid to dissolve about 230 grains of baryta: put this acid liquor into a glass vessel, which, during the operation, must be surrounded by ice: then take about 185 grains of the peroxide, rub it into a fine paste with a little water in an agate mortar, and put it into the acid liquor with a box-wood spatula; it soon dissolves without effervescence: to this solution add pure sulphuric acid drop by drop, stirring it with a glass rod, till it is in slight excess, which is known by the readiness with which the sulphate falls: then dissolve a second portion of the deutoxide and precipitate as before, taking care to use enough, but not too much, sulphuric acid. The liquor is now to be filtered, and the residue washed with a little water, so as to keep up the original measure by adding it to the first portion: a second and third washing of the residue with very small quantities of water may be advisable, and these liquors should be kept apart for the purpose of washing the filters in subsequent operations.

A fresh portion of the peroxide is then dissolved in the filtrated liquor and decomposed as before, filtering at every two operations, and washing the filter with the savings of the others. We thus proceed till the water is sufficiently oxygenated; when about two pounds of the peroxide have been consumed, the water will be united to about thirty times its volume of oxygen, which is as much as it will retain, unless some muriatic acid be added, in which case M. Thenard has made it retain 125 volumes.

When the water is sufficiently oxygenated, it is retained in the ice, and supersaturated with the peroxide of barium, which occasions the separation of flocculi of silica and alumina, coloured with a little oxide of iron and of manganese; the whole is then filtered as quickly as possible, and returned into the vessel surrounded by ice, the baryta is separated by sulphuric acid, and pure sulphate of silver is added to separate the muriatic acid, upon which the liquid, before milky, becomes suddenly clear. The sulphuric acid is ultimately separated by baryta, the liquor filtered and placed in a shallow vessel, under the air-pump receiver, containing a basin of sulphuric acid; the receiver being exhausted, the water evaporates and is absorbed by the acid, while the *peroxide of hydrogen*, being less vaporisable, remains: if it give out any oxygen, which sometimes happens from its containing impurities, a drop or two of weak sulphuric acid will prevent its further evolution.

The peroxide of hydrogen thus concentrated has the following properties: its specific gravity is 1.45; it is colourless and inodorous; it blisters the cuticle of the tongue, and has a peculiar metallic taste. It does not congeal when exposed to cold, unless diluted. It is rapidly decomposed at a heat below 212°, and very slowly at ordinary temperatures; it may be long kept at 32°. It is decomposed by the pile with the same phenomena as water. It is decomposed by all metals except iron, tin, antimony, and tellurium: the metals should be finely divided, or in powder: silver and oxide of silver decompose it very suddenly with the evolution of heat and light: platinum and gold produce the same phenomena; lead and mercury slowly separate the oxygen. Orpiment and powdered sulphuret of molybdenum act upon it with the same violence as silver; the peroxides of manganese and of lead also occasion its instant decomposition.

Chloride of Barium may be obtained by heating baryta in chlorine, in which case oxygen is evolved: or more easily, by dissolving carbonate of baryta in diluted muriatic acid. By evaporation, tabular crystals are obtained, soluble in 5 parts of water at 60°; and consisting, when dry, of

1 proportional of barium		=	70
1 „	chlorine	=	36
Equivalent of chloride of barium		=	106

Its taste is pungent and acrid; when exposed to heat, the water of crystallization, to the amount of about 14.5 per cent. (Phillips' *Ann. of Philos.* vi. 342), separates, and the dry chloride enters into fusion; the crystallized compound, therefore, may be considered as containing

1 proportional of dry chloride of barium		=	106	.. 85.48
2 „	water	=	18	.. 14.52
Equivalent of crystallized chloride of barium		=	124	100.

When a fragment of pure baryta is gently heated in muriatic acid gas, it becomes red-hot, and chloride of barium and water are the results, in the proportions producing the protohydrate. Chloride of barium is insoluble in alcohol.

Chlorate of Baryta was formed by Chenevix in the same way as chlorate of potassa, namely, by passing chlorine through an aqueous solution of baryta; but, in consequence of the similar solubility of chloride of barium and chlorate of baryta, considerable difficulty attended the separation of the products. It was effected by adding to the solution of the mixed salts, a solution of phosphate of silver in acetic acid, by which the chloride of barium was decomposed and resolved into chloride of silver and phosphate of baryta. Chlorate of baryta may, however, most readily be obtained by saturating chloric acid (obtained by the action of chlorine upon oxide of silver diffused in water) with hydrate of baryta. It crystallizes in quadrangular prisms, soluble in four parts of water, at 60°. It consists of

1 proportional of baryta		=	78
1 „	chloric acid	=	76
			154

Or of 1 proportional of barium		=	70
6 „	oxygen	=	48
1 „	chlorine	=	36
			154

The crystals contain 1 proportional of water.

Gay-Lussac procured chloric acid by the action of sulphuric acid upon this salt.—See page 152.

Iodide of Barium is easily formed by acting upon baryta by hydriodic acid, and evaporating the solution. It may also be formed by heating baryta in hydriodic gas; water and iodide of barium are the results. Its theoretical composition is

1 proportional of barium . . .	70 ..	35.9
1 ,, iodine . . .	125 ..	64.1
	195	100.

Iodate of Baryta is a very difficultly soluble compound. It is formed by adding iodine to baryta water: it falls in the form of a white powder, which is to be washed with distilled water: it consists of

1 proportional of baryta	= 78
1 ,, iodic acid	= 165
Equivalent of iodate of baryta . . .	= 243

The *hydriodate* is crystallizable and very soluble. When these salts are heated in vessels from which air is excluded, iodide of barium is the result.

Bromide of Barium is obtained by adding baryta to the etherial solution of bromine, or by saturating hydrobromic acid with baryta and evaporating to dryness: it is fusible, soluble in water and in alcohol, and crystallizes in opaque mammellated masses.

Bromate of Baryta has already been mentioned as a source of bromic acid (p. 159): it forms acicular crystals, slightly soluble in cold water, and producing vivid combustion on hot charcoal. It is obtained along with the bromide, by the action of bromine or solution of baryta.

Fluoride of Barium is best obtained, according to Berzelius, by adding fresh precipitated and moist carbonate of baryta to hydrofluoric acid; carbonic acid is expelled, and the fluoride remains in the form of a white powder, very sparingly soluble in water, but soluble in muriatic and nitric acids.

Nitrate of Baryta may be produced by dissolving the native carbonate in nitric acid, evaporating to dryness, redissolving, and crystallizing; it forms permanent octoëdral crystals, which are anhydrous: their forms have been described by Mr. Brooke (*Ann. of Phil., N. S.*, vii. 21). Its taste is acrid and astringent. It is soluble in 12 parts of cold and 4 of boiling water, and insoluble in alcohol; it is decomposed with decrepitation by a bright red heat, furnishing pure baryta. This decomposition should be effected in a porcelain crucible; for if platinum be used it is acted upon, and the baryta contaminated by oxide of platinum. It consists of

1 proportional of baryta	=	78
1 ,, nitric acid	=	54
		132

If a moderately strong solution of the nitrate of baryta be added to nitric acid, a precipitation of nitrate of baryta takes place, in consequence of the insolubility of the nitrate in the acid; hence in using nitrate of baryta as a test of the presence of sulphuric acid in nitric acid, the latter should be considerably diluted previous to its application.

Sulphuret of Barium is a brown compound, which acts upon water as already described, producing a crystallizable *hydrosulphuret of baryta*. It is formed by passing sulphuretted hydrogen over red-hot baryta in a glass tube, or by fusing a mixture of sulphur and baryta in a retort. It consists of

1 proportional of barium	=	70
1 ,, sulphur	=	16
Equivalent of sulphuret of barium	=	86

Its solution dissolves sulphur, but in what proportions has not been determined.

Hyposulphite of Baryta.—This salt is thrown down on pouring muriate of baryta into a solution, not too dilute, of hyposulphite of lime; it is a white powder, soluble without decomposition in muriatic acid; at a low heat it takes fire and sulphur burns off. When the solutions from which it is precipitated are dilute, it falls, after some minutes, in small crystalline grains, followed by a copious separation of the salt. According to Mr. Herschel this salt is a binhyposulphite, since it contains

1 proportional of baryta	=	78	61.9
2 ,, hyposulphuric acid	=	48	38.1
		126	100.

Edinburgh Philosophical Journal, vol. i. p. 20.

Sulphite of Baryta is insoluble in water, and formed by adding sulphite of potassa to muriate of baryta. Its theoretic composition is

1 proportional of baryta	=	78	.. 71
1 „ sulphurous acid . . .	=	32	.. 29
		110	100

It dissolves in sulphurous acid, and the solution furnishes crystals when very slowly evaporated.

Hyposulphate of Baryta.—When sulphurous acid gas is passed into water holding peroxide of manganese in suspension, a neutral solution is obtained, composed of sulphate and hyposulphate of manganese. These salts are decomposed by excess of baryta, and a soluble *hyposulphate of baryta* is formed, through which carbonic acid is passed, in order to saturate any excess of baryta; and the whole being heated to drive off carbonic acid which holds a little of the carbonate in solution, the hyposulphate of baryta is obtained, and may be purified by crystallization. The solution of this salt may be decomposed by the careful addition of sulphuric acid, and the *hyposulphuric acid* is thus obtained in solution.

This acid is inodorous, sour, and may be concentrated by exposure to a vacuum with sulphuric acid: it is decomposed by a heat below that of boiling water, sulphurous acid is disengaged, and sulphuric acid remains. It perfectly saturates bases, and forms soluble salts with baryta, strontia, lime, oxide of lead, and probably with all other bases (*Ann. de Chim. et Phys.* x. 312). The hyposulphate of baryta crystallizes in quadrangular prisms variously terminated; 100 parts of water at 60° dissolve about 14 parts. It consists of

1 proportional of baryta	=	78
1 „ hyposulphuric acid . .	=	72
2 „ water 8.5 × 2	=	18
		168

Or it may be stated as containing, in its dry state,

1 proportional of baryta	=	78
1 „ sulphuric acid	=	40
1 „ sulphurous acid	=	32
		150

hen hyposulphate of baryta is heated red, it gives out water and sulphurous acid, and leaves seven-tenths of its weight of neutral sulphate of baryta.

Sulphate of Baryta is an abundant natural product; it is insoluble in hot and cold water, and therefore precipitates whenever sulphuric acid, or a soluble sulphate, is added to any soluble salt of baryta; hence the solutions of baryta are accurate tests of the presence of sulphuric acid, and are also used in analysis to determine its quantity. If sulphuric acid be poured upon caustic baryta, the heat is so intense as to cause ignition. If the acid be boiled upon the finely-powdered or recently precipitated sulphate a portion is taken up; the whole of which, however, falls again upon diluting the solution with water.

The extreme insolubility of this sulphate renders the soluble salts of baryta the most delicate tests of the presence of sulphuric acid, of which a millionth part in solution may, according to Pfaff, be detected by a slight white cloud. When the sulphuric acid is in combination the test is somewhat less delicate, but it shows the presence of 1 part of sulphate of soda in 400,000 of water.

Sulphate of baryta is sometimes very obstinate in subsiding from water, and will not only long remain suspended, but even pass through filtering paper: heat, and a little excess of acid, generally facilitates its deposition.

Sulphate of baryta consists of 1 proportional of sulphuric acid and 1 of baryta.

Sulphuric acid	=	40	..	33.89
Baryta	=	78	..	66.11
Equivalent of sulphate of baryta .	=	118		100.

Native Sulphate of Baryta, Heavy Spar, or *Baroselenite,* is principally found in the mines of Westmorland and Cumberland, and in Transylvania, Hungary, Saxony, and Hanover. A variety met with in Derbyshire, is called *cawk.* It occurs massive, and crystallized in a great variety of forms. Its primitive figure is a rhomboidal prism, the angles of which are 101° 42′, and 78° 18′. It is harder than carbonate of lime, but not so hard as fluate of lime. Its specific gravity is 4.7.

When native sulphate of baryta is heated it decrepitates, and at a high temperature fuses into an opaque white enamel:

it was employed in the manufacture of *jasper ware* by the late Mr. Wedgwood. When formed into a thin cake with paste, and heated to redness, it acquires the property of phosphorescence. This was first ascertained by Vincenzo Cascariolo, of Bologna, whence the term *Bologna phosphorus* is applied to it. The artificial sulphate of baryta is used as a pigment, under the name of *permanent white.* It is very useful for marking phials and jars in a laboratory.

As the native sulphate is a common and abundant compound, several processes have been contrived for obtaining from it pure baryta. This may be effected by reducing the crystallized sulphate to a fine powder, and heating it red-hot for half an hour in a silver crucible with three parts of carbonate of potassa: the fused mass is then boiled repeatedly in water, till it no longer affords anything soluble in that liquid; the insoluble residue, consisting chiefly of carbonate of baryta, may be digested in dilute nitric acid, by which nitrate of baryta is formed, and which will yield the pure earth by exposure to heat as above-mentioned.

Another method consists in exposing to a red heat, in an earthen crucible, a mixture of six parts of finely-powdered sulphate of baryta, with one of powdered charcoal, for half an hour. This converts the sulphate into sulphuret, which is to be dissolved in hot water, the solution filtered and mixed with solution of carbonate of soda as long as it occasions a precipitate, which, when washed and dried, is carbonate of baryta. Or, by adding muriatic acid to the liquid sulphuret, sulphur is thrown down and sulphuretted hydrogen evolved, and muriate of baryta formed, which may be filtered off, and if required, decomposed by carbonate of potassa. Or the sulphuret, as it comes out of the crucible, may be thrown into *dilute* nitric acid, by which sulphuretted hydrogen is evolved, and nitrate of baryta formed, which may be separated from the remaining impurities by copious washings with hot water.

When sulphuret of baryta, in very fine powder, is boiled in a solution of carbonate of potassa or soda, a portion of the sulphate is also decomposed, and an equivalent proportion of carbonate of baryta formed. This decomposition of the sulphate is, however, never entire.

Phosphuret of Barium is produced by passing phosphorus over heated baryta; there is an intense action and a phosphate of baryta, together with a phosphuret of a metallic lustre, is obtained, which acts upon water, and affords a solution containing *Hypophosphite of Baryta.*—See Chap. IV., Sect. iv.

Hypophosphite of Baryta may be obtained by the same process as hypophosphite of lime; like the other hypophosphites it is very soluble in water, and difficultly crystallizable. (Dulong, *Ann. de Chim. et Phys.*, ii. 142.)

Phosphite of Baryta was obtained by Berzelius by adding muriate of baryta to phosphite of ammonia; a crust of phosphite of baryta was formed in 24 hours, consisting of

Phosphorous acid	24.31
Baryta	67.24
Water	8.45
	100.

Ann. de Chim. et Phys., ii. 231.

A red heat converts this phosphite into neutral phosphate of baryta. It dissolves in phosphorous acid, forming, apparently, a distinct *biphosphite of baryta.*

Phosphate of Baryta consists, according to theory, of

1 proportional of phosphoric acid	28	= 26.45
1 „ baryta	78	= 73.55
	106	100.

It is insoluble in water; and, therefore, formed by adding a solution of phosphoric acid or phosphate of soda to nitrate or muriate of baryta.

Berzelius has described a crystallizable *Biphosphate of Baryta*, obtained by digesting the phosphate in phosphoric acid; and a *Sesquiphosphate*, obtained by pouring the biphosphate into alcohol, which occasions a precipitate of a white tasteless powder, composed of 2 proportionals of baryta + 3 proportionals of acid. This, therefore, is a *sesquiphosphate.*

Berzelius has also announced two subphosphates of baryta. (Thomson's *Annals*, xv. 273.)

Selenite of Baryta, and *Seleniate of Baryta*, are in the form of insoluble white powders.

Carbonate of Baryta is found native. Artificially produced, it is a white compound nearly insoluble in water, which at 60°

takes about $\frac{1}{4300}$, and at 212° about $\frac{1}{2300}$th part. Water saturated with carbonic acid dissolves $\frac{1}{830}$. It has no action on vegetable colours, but is highly poisonous. It consists of

1 proportional of carbonic acid . . . . = 22
1 „ baryta . . . . = 78
100

When baryta water is added to solutions of the carbonated alkalis it abstracts their carbonic acid. Like the other carbonates, it is decomposed by the stronger acids with effervescence.

Native Carbonate of Baryta was first discovered at Anglesark, in Lancashire, by Dr. Withering, and hence acquired the name of *Witherite*. It has also been found in Wales, Cumberland, Durham, Westmorland, and Shropshire. Its primitive crystal is an obtuse rhomboid : sometimes it forms pyramidal six-sided prisms. That found in Lancashire is in globular masses of a radiated structure. It is useful as a source of pure baryta and its salts, and though very difficultly soluble in water, is poisonous. It dissolves very sparingly in solution of carbonic acid, whence the superiority of baryta water to lime water in some cases as a test of carbonic acid. The native carbonate of baryta is much more difficult of decomposition by heat than the artificial; if mixed with a little charcoal powder, and kept for some time in a red heat, carbonic oxide escapes, and pure baryta is formed.

Cyanuret of Barium is precipitated in the form of a white powder when hydrocyanic acid is mixed with baryta water.

Sulphocyanate of Baryta is formed by heating the ferrocyanate with sulphur : it is soluble in water, and forms brilliant acicular crystals, which are slightly deliquescent.

Borate of Baryta is an insoluble white powder, composed of 23 boracic acid, 78 baryta.

The soluble barytic salts furnish white precipitates of carbonate and sulphate of baryta, upon the addition of carbonate or sulphate of soda. They give a yellow tinge to the flame of spirit of wine. The sulphate is insoluble in nitric acid and in the alkalis, and very sparingly soluble in sulphuric acid.

Nearly all the barytic compounds are poisonous. Sulphate of baryta is, however, harmless; the safest antidote, therefore, is solution of sulphate of soda. (Orfila, *Traité de Poisons*, tom. i. 2me. p. 167.) The muriate of baryta has been employed in medicine, but the principal use of baryta is in the chemical laboratory. It is possible that pure baryta might be economically used for the decomposition of sulphate of soda, to obtain the pure alkali.

Section VI. STRONTIUM.

THIS metal is procured from the earth strontia by the same process as barium, which metal it resembles in appearance.

Oxide of Strontium, or the earth *Strontia*, is procured by the ignition of the pure nitrate; it is of a gray colour and very difficult of fusion when free from water; it forms a *pulverulent*, and a *crystallized hydrate*.

According to the researches of Stromeyer, (*Ann. de Chim. et Phys.* iii. 397,) Strontia consists of

84.669	strontium
15.331	oyygen
100.	

and as 15.3 : 84.6 :: 8 : 44.2; so that the number 44 may be assumed as the equivalent of strontium; and strontium, as will appear from the sequel, will consist of

1 proportional of strontium . . .	=	44
1 ,, oxygen . . .	=	8
		52

The pulverulent hydrate is probably a compound of 1 proportional of strontia + 1 water; and the crystallized hydrate, according to Mr. Dalton, is composed of 1 atom or proportional of strontia, and 12 of water. The crystals are soluble in half their weight of boiling water, and in about 50 parts at 60°. (HENRY.)

One part of strontia requires about 160 of water at 60° for its solution. *Strontia water* is transparent and colourless; it greens vegetable blues, and its taste is styptic and acrid.

Chlorine and Strontium.—This compound is commonly procured by dissolving carbonate of strontia in muriatic acid, and evaporating to dryness. It is of a gray colour, and an acrid taste. It dissolves in alcohol, and the solution burns with a purple-coloured flame. Its aqueous solution furnishes, upon evaporation, hexagonal prismatic crystals, which are deliquescent and soluble in two parts of water at 60°.

When chlorine is made to act upon strontium, oxygen is evolved, and chloride of strontium is formed. Sir H. Davy, from direct experiments (*Elements,* 345), ascertained that 50 parts of the chloride contain about 29 metal and 21 chlorine; and if we thence deduce the equivalent of strontium, it is about 49. But the number 44, above adopted, is more consistent with the best analysis of its saline compounds. Hence we may consider the chloride as consisting of

1 proportional of strontium . . .	= 44	55
1 „ chlorine . . .	= 36	45
	80	100

The crystallized muriate of strontia is considered by Mr. Phillips (*Ann. of Phil.* vi. 343) as including six atoms of water, and as composed, therefore, of

1 proportional of chloride of strontium	= 80	59.7
6 proportionals of water 9 × 6 . .	= 54	40.3
	134	100.

Chlorate of Strontia is a very soluble and deliquescent salt, difficultly crystallizable, and detonates when thrown upon red-hot coals with a beautiful purple light.

Iodide of Strontium may be formed as iodide of barium. Dissolved in water, and carefully evaporated, it furnishes delicate prismatic crystals of *Hydriodate of Strontia,* which, heated in close vessels, fuses, and becomes iodide of strontium by loss of water.

Iodate of Strontia is a very difficultly soluble compound; it is resolved at a red heat into oxygen, iodine, and strontia.

Bromide of Strontium and *Bromate of Strontia* have not been examined.

Fluoride of Strontium is a very difficultly soluble white powder.

Nitrate of Strontia crystallizes in octoëdra and dodecaëdra;

it is soluble in its weight of water at 60°. Its taste is pungent and cooling. At a red heat the acid is evolved and partly decomposed, and strontia remains. According to Stromeyer, the crystallized salt, as ordinarily prepared, contains no water of crystallization, but consists of 49.38 strontia + 50.62 nitric acid. It may, therefore, be considered as a compound of

1 proportional of strontia	=	52
1 ,, nitric acid	=	54
		106

This salt is used in the *red fire* employed at the theatres, which consists of 40 parts of dry nitrate of strontia, 13 of powdered sulphur, 5 of chlorate of potassa, and 4 of sulphuret of antimony. The chlorate and sulphuret should be separately powdered, and mixed together on paper with the other ingredients; a very small quantity of powdered charcoal may also be added.

Sulphuret of Strontium may be formed by fusing strontia and sulphur in a green glass tube; or by exposing the powdered sulphate to a red heat with charcoal. It dissolves in water with the same phenomena as sulphuret of potassa, and its solution furnishes, by cautious evaporation, crystals of *hydrosulphuret of strontia.*

Hyposulphite of Strontia is formed by passing sulphurous acid into the liquid sulphuret: it crystallizes in rhomboids permanent at common temperatures and soluble in about 5 parts of water at 60°. (Gay-Lussac, *Ann. de Chim.* lxxxv.) According to Mr. Herschel, this salt is doubly refractive. Its taste is bitter, and it is insoluble in alcohol.

Sulphite of Strontia is tasteless, and nearly insoluble.

Hyposulphate of Strontia is easily soluble, and crystallizes in hexangular tables, containing 22.5 *per cent.* of water.

Sulphate of Strontia occurs native. It is nearly insoluble, 1 part requiring 3840 of hot, and 4000 of cold, water for its solution. When heated with charcoal, its acid is decomposed, and *sulphuret of strontium* is formed, which affords nitrate by the action of nitric acid. This process, equally practicable upon sulphate of baryta, is sometimes adopted to obtain the earth. Sulphate of strontia dissolves in hot sulphuric acid, but is thrown down upon adding water. It consists of

1 proportional of strontia	. . .	=	52
1 ,, sulphuric acid	. .	=	40
			92

The *Native Sulphate of Strontia* is sometimes of a blue tint, and has hence been called *celestine*. Sometimes it is colourless and transparent. Its primitive form is a prism of 104° 48′ and 75° 42′ with a rhomboidal basis. It has been found at Strontian in Argyleshire; in the vicinity of Bristol; and at Montmartre near Paris. The finest crystallized specimens are accompanied with native sulphur, from Sicily. Its specific gravity is 3.2.

Phosphuret of Strontium has not been examined.

Hypophosphite of Strontia has been examined by Dulong: it is a very soluble and difficultly crystallizable salt.

Phosphite of Strontia.—When carbonate of strontia is dissolved in phosphorous acid a crystallized salt is obtained on evaporation: the crystals are decomposed by warm water, and a white powder falls, which is probably a neutral phosphite.

Selenite of Strontia is an insoluble white powder.

Phosphate of Strontia is an insoluble while salt, containing

1 proportional of strontia	. . .	=	52
1 ,, phosphoric acid	. .	=	28
			80

It is soluble in excess of phosphoric acid, which is not the case with phosphate of baryta. It is entirely decomposed by sulphuric acid. By igniting it with charcoal, *phosphuret of strontium* is obtained.

Carbonate of Strontia exists native. Artificially formed, it is a white powder, containing

1 proportional of strontia	. . . .	=	52
1 ,, carbonic acid	. .	=	22
			72

It is soluble in 1536 parts of hot water. When strongly heated with a little charcoal powder, it is decomposed, carbonic oxide is given off, and pure strontia remains.

Native Carbonate of Strontia or *Strontianite* is a rare mineral. It has a greenish tint, and occurs in radiated masses, and sometimes in acicular and hexaëdral crystals. It was first discovered in 1787 at Strontian in Argyleshire, whence the name of this earth ; it has also been found in Saxony and in Peru. Its specific gravity is 3.6.

This substance was first examined, and the peculiarities of strontia pointed out, by Professor Hope of Edinburgh, in 1791. His experiments are detailed in the *Philosophical Transactions of the Royal Society of Edinburgh*, vol. iv. p. 44.

Cyanuret of Strontium has not been examined.

Sulphocyanate of Strontia forms delicate prismatic crystals, which deliquesce on exposure.

Borate of Strontia was formed by Dr. Hope. It is a white powder soluble in 130 parts of water.

There is in many respects a resemblance between strontia and baryta, which has led to confusion in analysis.

The following are some of the most striking points of resemblance. They are both found native in the states of sulphate and carbonate only ; both sulphates are soluble in excess of sulphuric acid, and nearly insoluble in water ; they are decomposable by similar means, as well as the native carbonates ; they are both crystallizable from their hot aqueous solutions, and both attract carbonic acid. The carbonates are each soluble with effervescence in most of the acids ; but the native carbonates are not so easily acted on as the artificial. Pure ammonia precipitates neither one nor the other.

The following are essential distinctions. Baryta and all its salts, except the sulphate, are poisonous. The corresponding strontitic salts are innocent. Baryta tinges flame yellow ; strontia, red. Strontia has less attraction for acids than baryta ; hence the strontitic salts are decomposed by baryta. The greater number of the barytic salts are less soluble than those of strontia, and they differ in their respective forms and solubilities. Pure baryta is ten times more soluble in water than pure strontia.

Baryta and Strontia may also be distinguished from each other by the following process : dissolve the earth in muriatic, nitric, or any other acid with which it forms a soluble salt, then add excess of solution of sulphate of soda, filter, and test the clear fluid by carbonate of potassa : if any precipitate falls, the earth was strontia ; if none, baryta.

Section VII. Magnesium.

The metallic base of magnesia has not hitherto been obtained; but, when that earth is negatively electrized with mercury, the resulting compound decomposes water, and gives rise to the formation of *magnesia*. From the properties of the amalgam it appears that it is a white solid metal heavier than water, and highly attractive of oxygen.

Magnesia, or *Oxide of Magnesium*, is concluded, from experiments upon its combinations with the acids, to consist of

1 proportional of magnesium . . .	= 12
1 „ oxygen	= 8
Equivalent of magnesia	= 20

It may be procured by exposing the carbonate of magnesia to a red heat. Magnesia is a white insipid substance, which slightly greens the blue of violets, and reddens turmeric. But water which has been agitated with magnesia, when filtered through paper, does not produce similar effects (Henry). Its specific gravity is 2.3; it is almost infusible and insoluble in water. I once succeeded in agglutinating a small portion of this earth in the voltaic flame, and whilst exposed to this high temperature, it was perfectly fused by directing upon it the flame of oxygen and hydrogen. A mixture of magnesia and lime is scarcely more fusible than the pure earth. It does not absorb carbonic acid or moisture, nearly so rapidly as the other alkaline earths, and scarcely any heat is produced by pouring water upon it.

When magnesia is thrown down from its solutions by potassa, collected upon a filter, and dried at 212°, it still retains a considerable quantity of water, amounting to about one-fourth its weight; in this state, therefore, it is a *hydrate of magnesia*. It is insoluble in solutions of potassa and soda.

Native Magnesia is a very rare mineral, and has hitherto been found only at *Hoboken*, in New Jersey. Its colour is greenish white; its texture lamellar and soft. According to the analysis of Dr. Bruce, it consists of

70	magnesia
30	water
100	

These numbers nearly coincide with 1 proportional of magnesia and 1 of water, or $20 + 9 = 29$.

Chloride of Magnesium, consisting of

1 proportional of magnesium	. . . .	= 12
1 ,, chlorine	. . . .	= 36
		48

may be obtained by passing chlorine over red-hot magnesia; oxygen is expelled, and a substance obtained which moisture converts into muriate of magnesia. It cannot be obtained by evaporating its aqueous solution to dryness, for in that case muriatic acid escapes and magnesia remains. It appears, therefore, that this is one of those rare cases in which a true chloride becomes a true muriate by solution in water.

When chlorine is passed through a mixture of magnesia and water, a compound is obtained which has been termed *Chloride of Magnesia*, and which has been found useful in some processes of bleaching.

Muriate of Magnesia is very deliquescent, and difficultly crystallized. Its solution has a bitter saline taste. It dissolves in alcohol. Exposed to heat and air, muriatic acid flies off, and the magnesia remains pure. It consists of

1 proportional of magnesia	. . .	= 20	.. 35
1 ,, muriatic acid	. .	= 37	.. 65
		57	100

and its crystals contain, according to Dr. Thomson, 5 proportionals of water.

Muriate of magnesia is found in a few saline springs, and also in the water of the ocean. By evaporating a pint of sea-water we obtain

Common salt	. 180.5 grs.
Muriate of magnesia	. 23
Sulphate of magnesia	. 15.5
,, lime	. 7.1
	226.1

But it may be presumed that the elements of these salts, previous to the evaporation of the sea-water, were arranged thus:—

Common salt	180.5 grs.
Muriate of magnesia	18.3
,, lime	5.7
Sulphate of magnesia	21.6
	226.1

MURRAY'S *Analysis of Sea-Water, Edinburgh Phil. Trans.* vol. viii. p. 205.

The average specific gravity of sea-water is 1.026 or 1.028. It freezes at about 28.5°, and does not appear materially to differ in composition in different latitudes, provided it be taken from a sufficient depth. Near the mouths of rivers, and in the vicinities of melting ice or snow, its composition will of course vary. Traces of muriate and of hydriodate of potassa may also be found in it; and, according to Dr. Marcet (*Phil. Trans.* 1822), of triple sulphate of magnesia and potassa, and of muriate of ammonia. He has also detected in it a minute portion of carbonate of lime.

Muriate of Ammonia and Magnesia is a crystallizable salt, soluble in 6 parts of water at 60°.

Chlorate of Magnesia is a bitter deliquescent salt.

Muriate of Potassa and Magnesia is a triple salt, which, by very careful evaporation, may be obtained in rhombic crystals; but the constitution of this salt is so delicate, that it is liable to be separated into muriate of potassa and muriate of magnesia by water alone; and it is with certainty decomposed by alcohol, which takes up the magnesian muriate and leaves the other undissolved (Marcet, *Phil. Trans.* 1822, p. 456).

Iodide of Magnesium.—When iodine is heated with magnesia and water, both *hydriodate* and *iodate of magnesia* are formed. By concentrating the solution both salts are partly decomposed, and a brown flocculent iodide of magnesia is formed (resembling kermes in appearance), which, when heated, loses part of its iodine, and is changed into a *subiodide* (Henry, i. 593).

Hydriodate of Magnesia is deliquescent, and loses hydriodic acid by exposure to heat.

Hydrobromate of Magnesia is uncrystallizable and deliquescent.

Fluoride of Magnesium is obtained by digesting magnesia in hydrofluoric acid. Berzelius says that it is insoluble, and undecomposed at a red heat.

Nitrate of Magnesia crystallizes in rhomboidal prisms, deliquescent, and soluble in its weight of water. Its taste is cooling and bitter, and it is decomposed at a red heat. It contains, exclusive of water,

1 proportional of magnesia . . .	20	.. 27
1 „ nitric acid . . .	54	.. 73
	74	100

The water probably amounts to 6 proportionals.

Ammonio-Nitrate of Magnesia may be obtained by evaporating a mixed solution of nitrate of ammonia and nitrate of magnesia; it forms prismatic crystals of a bitter acrid taste, soluble in about 11 parts of water at 60°, and less deliquescent than their component salts separately.—Fourcroy, *Annales de Chimie*, iv. 215.

Sulphuret of Magnesium.—Sulphur and magnesia do not appear to form a complete sulphuret, for when melted together the compound does not dissolve in water; and when heated, the sulphur burns off.

Hyposulphite of Magnesia may be formed by boiling flowers of sulphur in solution of sulphite of magnesia; it is bitter, very soluble, but not deliquescent. Being more soluble in hot than cold water, it readily crystallizes as its solution cools; heated, sulphur escapes, but it is not very combustible.

Sulphite of Magnesia is prepared by passing sulphurous acid through water containing diffused magnesia. It forms tetraëdral crystals soluble in 20 parts of water at 60°.

Hyposulphate of Magnesia is difficultly crystallizable and readily soluble in water, but not deliquescent. It contains between 36 and 37 *per cent.* of water of crystallization.

Sulphate of Magnesia is a commonly occurring compound of this earth, much used in medicine as an aperient. When concentrated sulphuric acid is poured upon magnesia, intense heat is produced, and sometimes light. If the acid be dilute, and poured upon carbonate of magnesia, the latter is slowly dissolved with effervescence; and, upon evaporating the filtered solution, crystals of sulphate of magnesia may be obtained. It is largely consumed in the preparation of carbonate of magnesia. It crystallizes in four-sided prisms with reversed dihedral summits, or four-sided pyramids. Its taste is bitter. It is soluble in its own weight of water at 60°, and in three-fourths its weight of boiling water. When exposed to a red heat, it loses its water of crystallization, amounting to about 50 *per cent.*, but is not decomposed. It consists, independent of water of crystallization, of

1 proportional of magnesia	=	20	33.3
1 ,, sulphuric acid	=	40	66.7
		60	100.

In its crystallized state it contains, according to Gay-Lussac (*Ann. de Chim. et Phys.* xiii. 309), 51.43 *per cent.* of water. Crystallized sulphate of magnesia may therefore be considered as composed of 1 proportional of dry sulphate + 7 proportionals of water, or

Sulphate	=	60	48.8
Water	=	63	51.2
		123	100.

The aqueous solution of sulphate of magnesia furnishes a precipitate of carbonate upon the addition of the carbonates of potassa and soda, but carbonate of ammonia does not even render it turbid, unless heat be applied, in which case a precipitate of carbonate of magnesia is also thrown down. The alkaline bicarbonates occasion no precipitate when added to cold solution of sulphate of magnesia, but after some hours crystals of hydrated carbonate of magnesia are deposited.

This salt is usually obtained from sea-water, the residue of which, after the separation of common salt, is known by the name of *bittern*, and contains sulphate and muriate of magnesia; the latter is decomposed by sulphuric acid: a portion of muriate of magnesia often remains in the sulphate and renders it deliquescent: it is also occasionally obtained from saline springs; and sometimes by the action of sulphuric acid on magnesian limestone. It was once procured from the springs of Epsom in Surrey, and hence called *Epsom salt*. It has been found native, constituting the *bitter salt* and *hair salt* of mineralogists: it not unfrequently occurs as a fine capillary incrustation upon the damp walls of cellars and new buildings.

The sulphate of magnesia of commerce is occasionally adulterated with small crystals of sulphate of soda; the fraud is detected by the inferior weight of the precipitate, occasioned by adding carbonate of potassa; 100 parts of pure crystallized sulphate of magnesia furnishing a precipitate of about 40 parts of dry carbonate.

Ammonio-Sulphate of Magnesia may be obtained by mixing solution of sulphate of ammonia with solution of sulphate of magnesia; or by pouring ammonia into a solution of the sulphate of magnesia, in which case, part only of the magnesia is thrown down, the remainder forming with the sulphate of ammonia this triple salt. It crystallizes in octoëdra, and consists of

68	sulphate of magnesia
32	sulphate of ammonia
100	

(Fourcroy, *Annales de Chimie*, vi.)

Sulphate of Potassa and Magnesia forms rhomboidal crystals, scarcely more soluble than sulphate of potassa, and of a bitter taste. This salt appears, from Dr. Marcet's observations, to exist in sea-water.

Sulphate of Soda and Magnesia forms truncated rhombic crystals soluble in about 3 parts of water at 60°, and composed (Murray, *Ed. Ph. Tr.*, viii.) of sulphate of magnesia 32, sulphate of soda 39, water 29.

Phosphuret of Magnesia, not examined.

Hypophosphite of Magnesia may be obtained by boiling oxalate of magnesia for a long time with hypophosphite of lime, filtering and carefully evaporating the liquid. It crystallizes in octoëdra, containing 55 per cent. of water.

Phosphite of Magnesia requires 400 parts of water for solution, and is not crystallizable. An *ammonio-phosphite of magnesia* may be formed, which is crystallizable, and difficultly soluble.

Phosphate of Magnesia.—According to Fourcroy, four-sided prismatic crystals of phosphate of magnesia may be obtained by mixing the aqueous solutions of phosphate of soda and sulphate of magnesia. These consist of

1 proportional of	magnesia	= 20
1 ,,	phosphoric acid	= 28
7 ,,	water (9 × 7)	= 63
		111

They require about 15 parts of water at 60° for solution, and are slowly efflorescent. They are resolved by boiling water into an insoluble *subphosphate of magnesia* and a soluble *superphosphate.*

Ammonio-Phosphate of Magnesia is formed by mixing strong and warm solutions of phosphate of ammonia and phosphate of magnesia; it precipitates in the form of a white crystalline powder, or in small four-sided prisms, tasteless, and scarcely soluble in water, but readily soluble in dilute muriatic acid. Exposed to a high temperature it falls into powder, evolves ammonia, fuses with difficulty, and leaves an acid phosphate of magnesia. According to Fourcroy, it contains equal weights of phosphate of ammonia, phosphate of magnesia, and water. It has also been analysed by M. Anatole-Riffault (*Ann. de Chim. et Phys.*, xix. 90), according to whom it consists of

Phosphoric acid	30.667
Magnesia	16.808
Ammonia	13.880
Water	38.645
	100.

But Dr. Thomson questions the accuracy of this result, and says, that the compound dried in the open air consists of

1 proportional of	phosphate of magnesia	= 48
1 ,,	phosphate of ammonia	= 45
4 ,,	water (9 × 4)	= 36
		129

When phosphate of soda is added to solution of sulphate of magnesia, previously mixed with solution of carbonate of ammonia, a salt gradually falls which has generally been considered as identical with the previous salt, but which Berzelius regards as a subsalt: it exists in urine, and is a common ingredient in urinary calculi. If, after having mixed a solution of magnesia and of phosphate of soda with bicarbonate of ammonia, and having put some of the solution into a watch-glass or upon a piece of plate-glass, lines be traced upon the glass thus covered, with a glass rod, the salt will be deposited upon the traces. This appearance, the cause of which has not been adequately explained, has been ingeniously proposed by Dr. Wollaston as a test of the presence of magnesia; a similar appearance, however, ensues in other cases of granularly crystallized precipitates, but never where they are pulverulent.

This *subphosphate of ammonia and magnesia* is very sparingly soluble in water. It contains 38 per cent. of water; heated to redness it loses 52.44 per cent. of its weight, consisting in water and ammonia, and 47.56 per cent. of neutral phosphate of magnesia remains. It appears, therefore, to consist of

1	proportional of	magnesia	=	20
1	,,	ammonia	=	17
1	,,	phosphoric acid	=	28
5	,,	water (9 × 5)	=	45
Equivalent of ammonio-magnesian subphosphate			=	110

The discrepancies in the analyses of these compounds seem to have arisen from no sufficient distinction having been made between the neutral and the subsalt.

To separate magnesia from other earths, chemists have availed themselves of the formation of this triple phosphate. A mixture, for instance, of lime and magnesia may be dissolved in muriatic acid; and, upon the addition of bi-carbonate of ammonia, the lime is thrown down in the state of carbonate, but the magnesia is retained by the excess of carbonic acid. Filter and add a saturated solution of phosphate of soda in excess, and in a short time the ammonio-magnesian subphosphate falls down, 110 grains of which, dried at 100°, are equivalent to about 20 of magnesia. In occasionally employing this process, however, I have never been able to throw down the whole of the magnesia, a minute portion being retained in solution, and another falling with the lime.

Carbonate of Magnesia as generally procured by adding carbonated alkalis to a solution of sulphate of magnesia, is a white, insipid, and insoluble powder, which loses its acid at a red heat, and thus affords pure (calcined) magnesia. The composition of this precipitate appears to vary according to the circumstances under which it has been formed. Bucholz states that when precipitated from hot solutions, it contains 42 magnesia, 35 carbonic acid, 23 water per cent.; but if from cold, 33 magnesia, 32 carbonic acid, and 35 water. In Aikin's *Dictionary* the composition of the carbonate of magnesia of the shops is stated to be

Magnesia	45
Carbonic Acid	34
Water	21
	100

which numbers nearly correspond with those given by Bucholz, but are quite at variance with the theory of proportionals, unless we consider them as equivalent to

4 proportionals of magnesia . . . . . = 80
3 „ carbonic acid . . . . . = 66
4 „ water . . . . . . = 36

Berzelius (Thomson's *Annals*, xii. 30) has suggested the following as the composition of common carbonate of magnesia, and Dr. Henry appears to agree with him in opinion (*Elements*, i. 594):

3 atoms of carbonate (42 × 3) . = 126.... 72.77
1 „ tri-hydrate (20 + 27) . . = 47.... 27.23
173....100

Or of

Magnesia in the carbonate	34.34	45.82
„ hydrate	11.48	
Carbonic acid		38.42
Water		15.76
		100

It appears then, that a true anhydrous carbonate of magnesia composed of 1 proportional of acid and 1 of base, or 22 + 20 = 42, has not been formed artificially, but that the elements are combined in those proportions, in the native carbonate from the East Indies, mentioned below.

When bicarbonate of potassa or soda are added to sulphate of magnesia, or when carbonic acid is passed through water in which magnesia is diffused, and the clear liquor afterwards poured off, small four-sided prismatic crystals are, after a time, spontaneously deposited, composed, according to Aikin (*Dictionary*), of

Magnesia	25
Carbonic acid	50
Water	25
	100

from which proportions they may be regarded as a hydrated *bicarbonate of magnesia.* But Berzelius has stated the following as the composition of these crystals (*Edinb. Phil. Journ.*, i. 73): magnesia 29.583, acid 31.503, water 38.914: numbers which would lead to the inference of its being a hydrated carbonate, and not a bicarbonate, and which nearly agree with

1	proportional of magnesia		20	28.60
1	„ carbonic acid		22	32.
3	„ water (9 × 3)	=	27	39.40
			69	100

Magnesia dissolved in water by excess of carbonic acid is an excellent substitute, in many cases of gravel and calculus, for soda-water and other alkaline remedies.

There are other processes by which carbonate of magnesia is procured, such as decomposing *bittern* or impure muriate of magnesia of the sea-salt works, by magnesian limestone; or by crude carbonate of ammonia, produced by the distillation of bone; in the latter case muriate of ammonia and carbonate of magnesia result; the solution of the muriate is evaporated to dryness and sublimed with chalk; carbonate of ammonia is thus reproduced for the decomposition of a second portion of bittern, and so on.

Carbonate of magnesia was first used in medicine early in the last century. It has been found native in Piedmont and Moravia, constituting the mineral called *magnesite.* It has also been found at Hoboken (in North America) in veins in a serpentine rock, accompanying the native hydrate. It is generally white and friable, and in some places in fine acicular crystals.

A variety of native carbonate of magnesia, brought from the East Indies by Mr. Babington, has been described and analysed by Dr. Henry (*Annals of Philos.*, i. 254). It is white, massive, hard, of a conchoidal fracture, and translucent at the edges; specific gravity 2.6. It slowly dissolves in acids, and is composed of

Magnesia	46.
Carbonic acid	51.
Insoluble matter	1.5
Water	0.5
Loss	1.
	100

This is therefore a compound of one proportional of magnesia, and one of carbonic acid.

Ammonio-carbonate of Magnesia is obtained by mixing excess of bicarbonate of ammonia with muriate of magnesia; it forms very small crystals, which are gradually deposited, and which are decomposed by hot water, and by exposure to air.

Carbonate of Potassa and Magnesia.—When excess of bicarbonate of potassa is mixed with muriate of magnesia, no precipitation ensues, but in a few days crystals are formed, composed, according to Berzelius (*Ed. Phil. Journal*, ii. 67), of

Potassa	18.28
Magnesia	15.99
Carbonic acid	34.49
Water	31.24
	100.

Boiling water decomposes this salt.

Carbonate of Soda and Magnesia is formed as the triple potassa salt, by bicarbonate of soda; but it is not so easily decomposed; and, accordingly, when magnesia is precipitated by excess of carbonate of soda, a portion of the triple soda salt is retained, and not easily washed away.

Borate of Magnesia may be formed artificially, by boiling boracic acid and magnesia in water; as the solution cools, it deposits the salt in crystalline grains. Paper, which has been moistened with it, burns with a fine green flame; at a red heat it runs into a transparent glass. It occurs native in a mineral called *boracite*, hitherto only found in the duchy of Luneburgh. Its primitive form is the cube, but the edges and angles are generally replaced by secondary planes, and four of the angles are always observed to present a greater number of facets than the other four: these crystals become electric by heat; the most complex angles being rendered positive, and the simplest negative. It sometimes contains lime.

The salts of magnesia are, for the greater part, soluble in water, and afford precipitates of magnesia, and of carbonate of magnesia, upon the addition of pure soda, and of carbonate of soda. Phosphate of soda occasions no immediate precipitate when added to a magnesian salt, but the addition of ammonia causes a white precipitate of the triple ammonio-magnesian phosphate.

The fossils which contain magnesia are generally soft and apparently unctuous to the touch; they have seldom either lustre or transparency, and are generally more or less of a green colour. *Steatite* or *soapstone, talc,* and *asbestos,* may be taken as instances. The *chrysolite* also contains more than half its weight of magnesia. The mineral called *bitter spar,* of which the finest specimens come from the Tyrol, contains 45 *per cent.* carbonate of magnesia, 52 carbonate of lime, and a little iron and manganese. Its primitive crystal is a rhomboid nearly allied to that of carbonate of lime; its angles being 106° 20′, and 73° 80′. It is of a yellowish colour, and a pearly lustre; semi-transparent and brittle. A variety found at *Miemo* in Tuscany, has been called *Miemite.* The species of marble, termed *Dolomite,* found in the Alps, and at Icolmkill in Scotland, contains also a large quantity, generally 40 *per cent.* of carbonate of magnesia. The same may be said of the magnesian limestone of Derby and Nottingham: it is generally of a yellowish colour, and less rapidly soluble in dilute muriatic acid, than the purer limestone, whence the French have termed it *chaux carbonatée lente.* The lime which it affords is much esteemed for cements, but for agricultural purposes it is often mischievous, in consequence of its remaining caustic for a very long time, and thus injuring the young plant.

The separation of magnesia and lime is a problem of some importance in analytical chemistry, as they often exist together in the same mineral, more especially in the varieties of magnesian limestone. When solution of carbonate of ammonia is added to the mixed solution of lime and magnesia in nitric or muriatic acids, carbonate of lime falls, and the magnesia is retained in solution, and may be separated by boiling with carbonate of potassa: this method, however simple, is not susceptible of great accuracy, for a portion of carbonate of lime will always be retained along with the magnesia in solution, and a triple ammoniaco-magnesian salt is also formed. Mr. R. Phillips (*Quarterly Journal*, vi. 317) proposes the following process: "To the muriatic or nitric solution of lime and magnesia, add sulphate of ammonia in sufficient quantity; evaporate the mixture gradually to dryness, and then heat to redness till it ceases to lose weight, by the volatilization of the muriate or nitrate of ammonia formed: note the weight of the mixed salt, reduce it to powder, and wash it with a saturated solution of sulphate of lime till all the sulphate of magnesia appears to be dissolved; dry the sulphate of lime left, and by deducting its weight from that of the mixed sulphates the quantity of sulphate of magnesia dissolved will appear." After repeated trials of the various modes of separating lime and magnesia, I am induced to consider the following as tolerably correct. To the mixed solution of lime and magnesia add oxalate of ammonia slightly acid, collect the precipitate, wash and dry it at 100°, 82 parts indicate 28 of lime. If nitric or muriatic acid were used for solution, the magnesia may afterwards be obtained by evaporation and heating the residue to redness in a platinum crucible till it ceases to lose weight. If sulphuric acid were the solvent, the same operation affords dry sulphate of magnesia, of which 60 parts are equivalent to 20 magnesia.

APPENDIX,

CONTAINING

TABLES OF WEIGHTS AND MEASURES.

APPENDIX.

ENGLISH WEIGHTS AND MEASURES.

The English *troy* pound is subdivided into twelve ounces, and each ounce is equal to 480 grains. The subdivisions of the troy ounce, called *Apothecaries' weight*, are into 8 drachms, each drachm into 3 scruples, and each scruple into 20 grains. The troy ounce is also sometimes divided into 20 pennyweights, of 24 grains each. These are the weights generally employed by chemists, but for philosophical purposes ambiguity is most easily avoided by employing the grain as integer: and the laboratory should be provided with good sets of weights, from 1000 grains downwards; the grain should be decimally subdivided into tenths and hundredths.

The standard of most articles bought and sold in common life is the *avoirdupois* pound, which is equal to 7000 troy grains, and is divided into 16 ounces, of 437.5 troy grains each. The avoirdupois ounce is legally divided into 16 drachms, of 27.34375 grains each; but this division is rejected in all ordinary cases, in consequence of the confusion likely to result between the troy and avoirdupois drachm, so that the term *drachm* is almost exclusively employed to denote the eighth part of a troy ounce, or 60 grains.

For measures of capacity, the *wine pint* is usually employed, which corresponds to 28.875 cubical inches of water, at a temperature of 60°. It is subdivided into 16 ounces; the ounce into 8 drachms. Two pints make a quart, and 4 quarts a gallon.

The *ale pint* contains 35.25 cubical inches of water, at 60°.

For chemical use, the most convenient measure is the bulk occupied by the troy ounce of distilled water, which may be subdivided into 480 grains, and which is equal to 1.8047 cubical inches.

The length of the pendulum, vibrating seconds *in vacuo*, in the latitude of London (51° 31′ 8″.4 North) at the level of the sea, and at the temperature of 62°, is = 39.13929 inches of Sir George Shuckburgh's standard scale.—Kater, *Phil. Trans.* 1819, p. 415.

In the following Tables are shown the subdivisions of the English troy and avoirdupois pounds, and of the English wine gallon, and their correspondence with the French *gramme* and *litre.*

ENGLISH WEIGHTS AND MEASURES.

TROY WEIGHT.

Pound.	Ounces.	Drms.	Scruples.	Grains.	Grammes.
1	12	96	288	5760	372.96
	1	8	24	480	31.08
		1	3	60	3.885
			1	20	1.295
				1	0.06475

AVOIRDUPOIS WEIGHT.

Pound.	Ounces.	Drms.	Grains.	Grammes.
1	16	256	7000	453.25
	1	16	437.5	28.328
		1	27.34375	1.7705

WINE MEASURE.

Gal.	Pints.	Ounces.	Drms.	Cub. Inch.	Litres.
1	8	128	1024	231	3.78515
	1	16	128	28.875	0.47398
		1	8	1.8047	0.02957
			1	0.2256	0.00396

The IMPERIAL GALLON, *now substituted for all other measures, is one-fifth more than the old wine gallon* (30 *Imperial* = 36 *Wine*), *and one-sixtieth less than the old ale gallon* (31.5 *Imperial* = 30 *Ale*). *It contains* 10 *pounds of water, of* 7000 *grains each (avoirdupois pounds)* = 70,000 *grains* = 277.273 *cubic inches of water at* 62°.

FRENCH WEIGHTS AND MEASURES.

The French metrical system is founded on a single standard of length, called a *metre*, and which is equivalent to the ten millionth part of the arc of the meridian, extending from the equator to the pole. The length of the metre, at the temperature of 32°, as ascertained by Captain Kater (*Phil. Trans.* 1818), is 39.37079 English inches.

The French measures increase and decrease in decimal proportions, a distinctive prefix being put to the term by which the integer is called. These prefixes are *deca*, *hecto*, *kilo*, and *myria*, taken from the Greek numerals, to express the *multiplication* of the integer by 10, 100, 1000, and 10000 respectively: and *deci*, *centi*, and *milli*, from the Latin numerals, to express the division of the integer by 10, 100, or 1000; as in the following Table:—

		Metres.			Metre.
1 Myriametre	=	10000	1 Metre	=	1
1 Kilometre	=	1000	1 Decimetre	=	0.1
1 Hectometre	=	100	1 Centimetre	=	0.01
1 Decametre	=	10	1 Millimetre	=	0.001

The metre is the integer of the measure of length, and from it all measures of surface, capacity, and weight, are deduced as follows:—

For square dimensions, the metre, or its parts squared, are employed. When used for measuring land the term *are* is adopted, which is a decametre squared. An *hectare*, or 100 *ares*, is about equal to 2 English acres.

For the integer of the measure of capacity, the cubed decimetre is employed, under the name of *litre*, which is about equal to $2\frac{1}{8}$ English wine pints.

For the integer of the measure of weight, the weight of a cubic centimetre of distilled water, at 32°, has been adopted: it is called a *gramme*, and is equal to 15.4 English grains.

The following are the principal Tables of French Weights and Measures, which will be found useful in the laboratory. In *Appendix* II. of Aikin's *Dictionary*, the reader will find several others, showing the relation of the French to the English standards.

FRENCH WEIGHTS AND MEASURES.

Measures of Length.

		English inches.		Mil.	Fur.	Yds.	Feet.	In.
Millimetre	=	.03937						
Centimetre	=	.39371						
Decimetre	=	3.93710						
Metre	=	39.37100						
Decametre	=	393.71000	=	0	0	10	2	9.7
Hecatometre	=	3937.10000	=	0	0	109	1	1
Kilometre	=	39371.00000	=	0	4	213	1	10.2
Myriometre	=	393710.00000	=	6	1	156	0	6

Measures of Capacity.

		Cubic inches.		*English.*			
				Tons.	Hogs.	Wine G.	Pints.
Millilitre	=	.06103					
Centilitre	=	.61028					
Decilitre	=	6.10280					
Litre	=	61.02800	=	0	0	0.	2.1133
Decalitre	=	610.28000	=	0	0	2.	5.1352
Hecatolitre	=	6102.80000	=	0	0	26.419	
Kilolitre	=	61028.00000	=	1	0	12.19	
Myriolitre	=	610280.00000	=	10	1	58.9	

Measures of Weight.

		English grains.		*Avoirdupois.*		
				Poun.	Oun.	Dram.
Milligramme	=	.0154				
Centigramme	=	.1544				
Decigramme	=	1.5444				
Gramme	=	15.4440				
Decagramme	=	154.4402	=	0	0	5.65
Hecatogramme	=	1544.4023	=	0	3	8.5
Kilogramme	=	15444.0234	=	2	3	5
Myriogramme	=	154440.2344	=	22	1	2

TABLE OF THE SPECIFIC GRAVITY OF WATER, AT EVERY DEGREE OF TEMPERATURE, FROM 30° TO 80° FAHR.

The following Table is given by Mr. Gilpin, in the 84th volume of the *Philosophical Transactions*, and is of essential use for taking the specific gravities both of solids and fluids, by enabling the operator to reduce the weight or bulk of the distilled water employed in any case, to that which it would have at any other common temperature, and particularly to 60°, which is the usual standard.

Thus, for example, since the specific gravity of water at 47° is 1.0008, and at 60° is 1.00000, and (consequently 10008 grains, at 47°, are equal in bulk to 10000 grains at 60°,) it follows that it would require 252.708 grains, at 47°, to equal the space of a cubic inch : for 10000 : 10008 :: 252.506, (the weight of a cubic inch at 60°,) : 252.708.

The remarkable anomaly of the specific gravity of water *decreasing* through all the degrees of temperature below 40°, or thereabouts, that it remains uncongealed, has been noticed under the article HEAT ; but the difference for one or two degrees above or below 40° is so trifling, that it has hardly yet been ascertained with perfect accuracy.

Fahr.	Sp. Grav.	Fahr.	Sp. Grav.	Fahr.	Sp. Grav.	Fahr.	Sp. Grav.
30°	1.00074	43°	1.00090	56°	1.00031	69°	0.99906
31	1.00078	44	1.00088	57	1.00024	70	0.99894
32	1.00082	45	1.00086	58	1.00016	71	0.99882
33	1.00085	46	1.00083	59	1.00008	72	0.99869
34	1.00088	47	1.00080	60	1.00000	73	0.99856
35	1.00090	48	1.00076	61	0.99991	74	0.99843
36	1.00092	49	1.00072	62	0.99981	75	0.99830
37	1.00093	50	1.00068	63	0.99971	76	0.99816
38	1.00094	51	1.00063	64	0.99961	77	0.99802
39	1.00094	52	1.00057	65	0.99950	78	0.99788
40	1.00094	53	1.00051	66	0.99939	79	0.99774
41	1.00093	54	1.00045	67	0.99928	80	0.99759
42	1.00092	55	1.00038	68	0.99917		

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